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Interline Dynamic Voltage Restorer for Induction motor applications

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ABSTRACT: *An interline dynamic voltage restorer (IDVR) is a new device for sag mitigation which is made of several dynamic voltage restorers (DVRs) with a common DC link, where each DVR is connected in series with a distribution feeder. During sag period, active power can be transferred from a feeder to another one and voltage sags with long durations can be mitigated. IDVR compensation capacity, however, depends greatly on the load power factor and a higher load power factor causes lower performance of IDVR. To overcome this limitation, a new idea is presented in this paper which allows reducing the load power factor under sag condition, and therefore, the compensation capacity is increased. The proposed IDVR employs two cascaded H-bridge multilevel converters to inject AC voltage with lower THD and eliminates necessity to low-frequency isolation transformers in one side. The validity of the proposed configuration is verified by simulations in the Matlab/Simulink environment. Then, experimental results on a scaled-down IDVR are presented to confirm the theoretical and simulation results.*

Key words: Back-to-back converter, cascaded H-bridge, interline dynamic voltage restorer (IDVR), minimum energy, power quality (PQ), voltage sag, Induction motor.

I. INTRODUCTION

Nowadays, a lot of people exertions need aid accomplished for control personal satisfaction change. The voltage sag may be a standout amongst those significant power quality challenges for touchy loads [1]. Depending upon the duration and magnitude of the voltage sag/swell the damages on the consumers will be different. [2], [3]. The secondary costs about these harms defend the expanding interest towards voltage sag mitigation techniques. Dynamic voltage restorers (DVRs) are a power electronic device used for compensating the voltage sag mitigation in the distribution side of power system [4]. Voltage sag can be compensated using the DVR by purely injecting a reactive power or combination of active and reactive power, but some amount of voltage drop is only compensated by injecting the reactive power attained. The compensation capacity is mainly depend upon the greatest achievable inverter voltage, the energy stored in the dc link, duration of voltage sag [5]-[8]. The compensation capability with the least energy is limited when the voltage sag exceeds some certain value, which is a function of load power factor [5]. Even though this method reduces energy consumption, the long term and deeper voltage sag cannot be completely compensated by injecting the reactive power. Therefore to have a complete compensation, it is necessary to inject both active and reactive power in distribution side. An interline DVR (IDVR) has been proposed in [9].The IDVR consist of several DVRs with a common DC link. It protects the touchy loads against voltage sags, by locating each DVR in an independent feeder. Therefore one of the DVRs in IDVR starts to compensate the voltage sag;other DVRs replenish the common dc-link voltage.

In [10], the capability of DVR is extended to mitigate deeper voltage sags. In this shunt reactance is parallelconnected with the load to decrease the load power factor during the voltage sag condition.

In [11], the capacity of IDVR in compensating the sag at high power factor is improved by 7-level cascaded H-bridge converters with common dc link. To overcome this limitation, a topology is proposed in this paper which reduces the total harmonics and which not only improves the capacity and ability of compensator to mitigate very deep sags at high and moderate factors and also displacement factor is improved by PQ sharing.

II. OPERATING PRINCIPLE OF IDVR

A simple IDVR which is shown in Fig. 1 consists of twoback-to-back voltage-source converters (VSC) with a commondc link. By using this topology, it is possible to transfer activepower from a feeder to another one during the sag condition andto mitigate deeper and longer voltage sags (Fig. 1).

Consider, for example, the condition in which a voltage sagoccurs in feeder1 and DVR1 starts to compensate it. Assuming $P_{S1}$and P_{L1} are source1 and load1 active powers, then the injected active power by DVR1 would be

$$P_{DVR1} = P_{L1} - P_{S1} \quad (1)$$

Using the demonstrated phasor diagram in Fig. 2(a), (1) can be written as

$$P_{DVR1} = V_{L1}I_{L1}\cos(\varphi_1) - V_{S1}I_{L1}\cos(\varphi_1 - \alpha)(2)$$

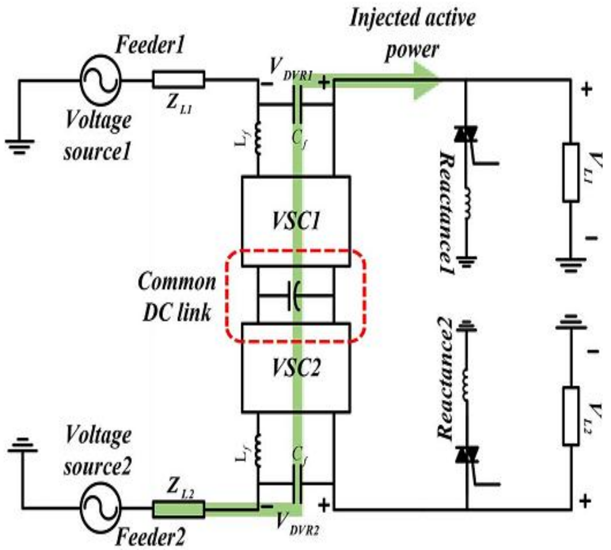

Fig.1. Power circuit schematic of the IDVR with active power-exchanging capability

Where it is obvious that load current is equal to source current due to series connection of DVR1 with load1. Whenminimum energy method is adopted for sag compensation, (2)is modified as shown in (3) at the bottom of the page. Moreover,active power, which is drawn by DVR2 from feeder2 can be derived from Fig. 2(b) as follows:

$$P^{ME}_{\mathrm{DVR1}} = \begin{cases} 0, & \text{if } V_{S_1} \geq V_{L_1}\mathrm{Cos}(\varphi_1) \\ V_{L_1} I_{L_1}\left(\mathrm{Cos}(\varphi_1) - V_{S_1}/V_{L_1}\right), & \text{if } V_{S_1} < V_{L_1}\mathrm{Cos}(\varphi_1) \end{cases} \quad (3)$$

$$P_{DVR2} = V_{L2} I_{L2}(\cos(\varphi_2 - \beta) - \cos(\varphi_2)) \quad (4)$$

Where injected voltage by DVR2 during the sag period leadsto a phase difference between and which is defined asβ. According to (4) and [9], the maximum transferable active

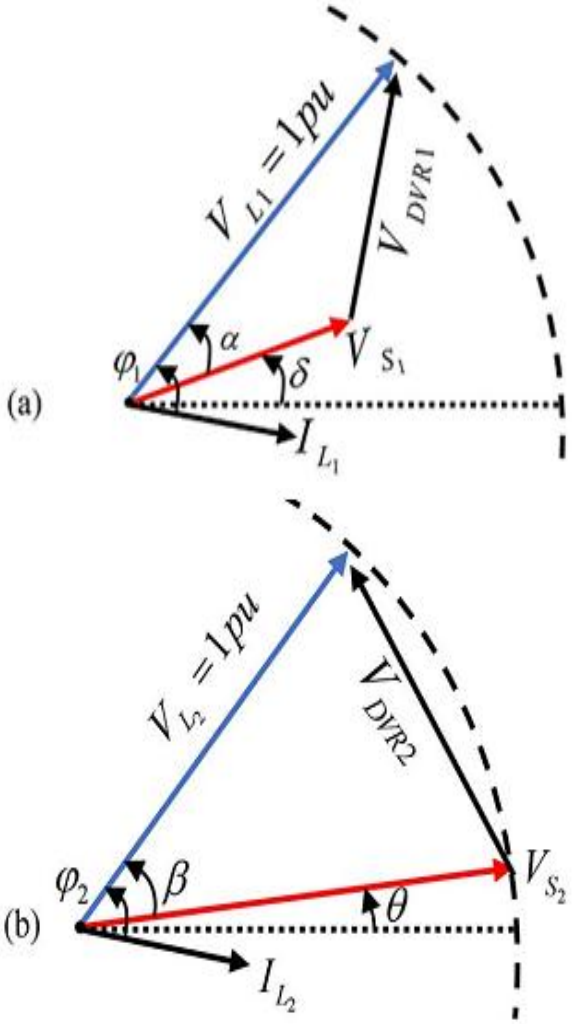

Fig.2. Phasor diagram of the IDVR during voltage sag compensation: (a) DVR1 injected voltage and (b) DVR2 injected voltage.

III. CHB-BASED IDVR

Most of the published literature in the field of DVR and IDVR deals with VSCs realized using two-level converters. But in high-voltage and high-power applications, a CHB-based multilevel converter is a more attractive solution and its application in an IDVR is introduced in this paper. Among the multilevel topologies, the cascaded H-bridge converter is of greater interest for IDVR topology because of its modular structure, reaching medium output voltage levels using only standard low voltage mature technology components, and higher reliability.

Moreover, low-frequency modulation techniques and fault-tolerant algorithms can be easily applied to CHB-based IDVRs[17]–[19].

In a CHB converter, depending on the number of voltage levels which have to be synthesized, separate dc links are needed. In the IDVR structure, however, back-to-back connection of two CHB converters and the use of low frequencyisolation transformers in one side, distinct dc links are easilyprovided. Furthermore, this structure eliminates the necessityfor isolation transformers on one side which leads to lowersize, weight, and cost. The number of H-bridge cells in a CHBconverter is chosen according to the required ac voltage andthe voltage rating of power switches. Fig.3 demonstrates asingle-phase 7-level CHB-based IDVR which is used in thesimulation study and experimental investigation. Although a7-level back-to-back converter is chosen for the study in thispaper, the proposed control strategy can be applied to anynumber of voltage levels and there is no limitation from thispoint of view. In other words, the generated voltage referencesby the control system will be synthesized by the CHB converterthrough well-known multilevel modulation techniques. Theonly issue is related to keeping voltage balance among dc-linkcapacitors which has been addressed in [17] and [20] for anynumber of voltage levels.

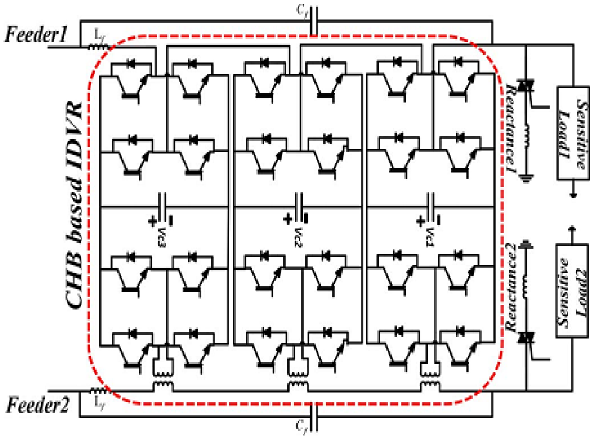

Fig.3. Proposed IDVR structure.

IV. INDUCTION MOTOR

An asynchronous motor type of an induction motor is an AC electric motor in which the electric current in the rotor needed to produce torque is obtained by electromagnetic induction from the magnetic field of the stator winding. An induction motor can therefore be made without electrical connections to the rotor as are found in universal, DC and synchronous motors. An asynchronous motor's rotor can be either wound type or squirrel-cage type.

Three-phase squirrel-cage asynchronous motors are widely used in industrial drives because they are rugged, reliable and economical. Single-phase induction motors are used extensively for smaller loads, such as household appliances like fans. Although traditionally used in fixed-speed service, induction motors are increasingly being used with variable-frequency drives (VFDs) in variable-speed service. VFDs offer especially important energy savings opportunities for existing and prospective induction motors in variable-torque centrifugal fan, pump and compressor load applications. Squirrel cage induction motors are very widely used in both fixed-speed and variable-frequency drive (VFD) applications. Variable voltage and variable frequency drives are also used in variable-speed service.

In both induction and synchronous motors, the AC power supplied to the motor's stator creates a magnetic field that rotates in time with the AC oscillations. Whereas a synchronous motor's rotor turns at the same rate as the stator field, an induction motor's rotor rotates at a slower speed than the stator field. The induction motor stator's magnetic field is therefore changing or rotating relative to the rotor. This induces an opposing current in the induction motor's rotor, in effect the motor's secondary winding, when the latter is short-circuited or closed through external impedance. The rotating magnetic flux induces currents in the windings of the rotor; in a manner similar to currents induced in a transformer's secondary winding(s). The currents in the rotor windings in turn create magnetic fields in the rotor that react against the stator field. Due to Lenz's Law, the direction of the magnetic field created will be such as to oppose the change in current through the rotor windings. The cause of induced current in the rotor windings is the rotating stator magnetic field, so to oppose the change in rotor-winding currents the rotor will start to rotate in the direction of the rotating stator magnetic field. The rotor accelerates until the magnitude of induced rotor current and torque balances the applied load. Since rotation at synchronous speed would result in no induced rotor current, an induction motor always operates slower than synchronous speed. The difference, or "slip," between actual and synchronous speed varies from about 0.5 to 5.0% for standard Design B torque curve induction motors. The induction machine's essential character is that it is created solely by induction instead of being separately excited as in synchronous or DC machines or being self-magnetized as in permanent magnet motors.

For rotor currents to be induced the speed of the physical rotor must be lower than that of the stator's rotating magnetic field ($\boldsymbol{n_s}$); otherwise the magnetic field would not be moving relative to the rotor conductors and no currents would be induced. As the speed of the rotor drops below synchronous speed, the rotation rate of the magnetic field in the rotor increases, inducing more current in the windings and creating more torque. The ratio between the rotation rate of the magnetic field induced in the rotor and the rotation rate of the stator's rotating field is called slip. Under load, the speed drops and the slip increases enough to create sufficient torque to turn the load. For this reason, induction motors are sometimes referred to as asynchronous motors. An induction motor can be used as an induction generator, or it can be unrolled to form a linear induction motor which can directly generate linear motion.

Synchronous Speed:

The rotational speed of the rotating magnetic field is called as synchronous speed.

$$N_s = \frac{120 \times f}{P} \quad (RPM) \qquad (5)$$

Where, f = frequency of the supply
P = number of poles

Slip:

Rotor tries to catch up the synchronous speed of the stator field, and hence it rotates. But in practice, rotor never succeeds in catching up. If rotor catches up the stator speed, there won’t be any relative speed between the stator flux and the rotor, hence no induced rotor current and no torque production to maintain the rotation. However, this won't stop the motor, the rotor will slow down due to lost of torque, and the torque will again be exerted due to relative speed. That is why the rotor rotates at speed which is always less the synchronous speed.

The difference between the synchronous speed (Ns) and actual speed (N) of the rotor is called as slip.

$$\%\ \text{slip} \quad s = \frac{N_s - N}{N_s} \times 100 \qquad (6)$$

IV. MATLAB/SIMULINK RESULTS

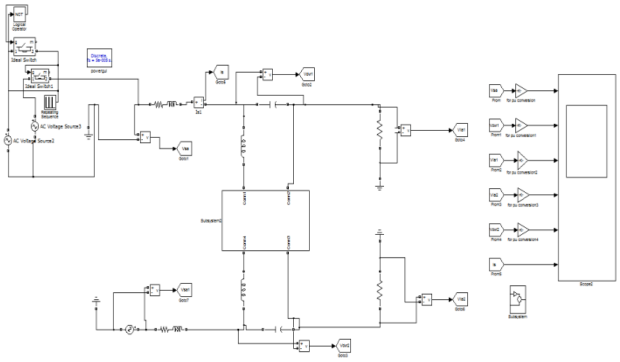

Fig.4 simulink model of IDVR block diagram

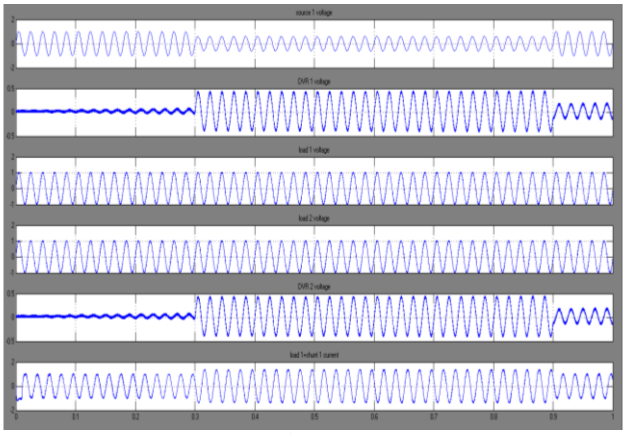

Fig.5 Investigating the IDVR performance when the proposed method is applied for a sag with a depth of 0.4 p.u.

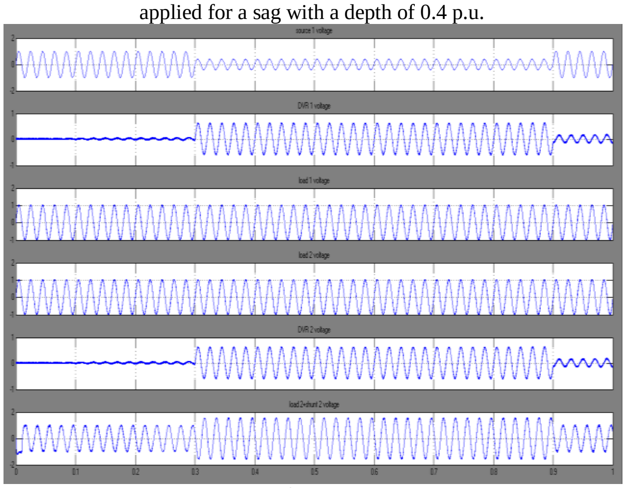

Fig.6 Investigating the IDVR performance when the proposed method is applied for a sag with a depth of 0.6 p.u.

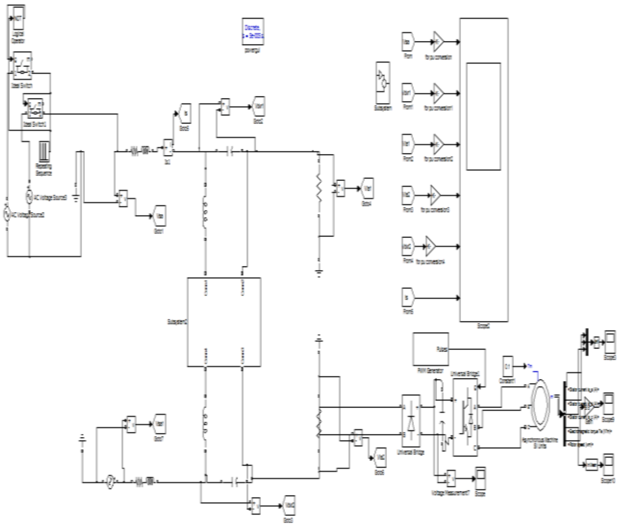

Fig.4 Simulink model of IDVR block diagram with Induction Motor drive.

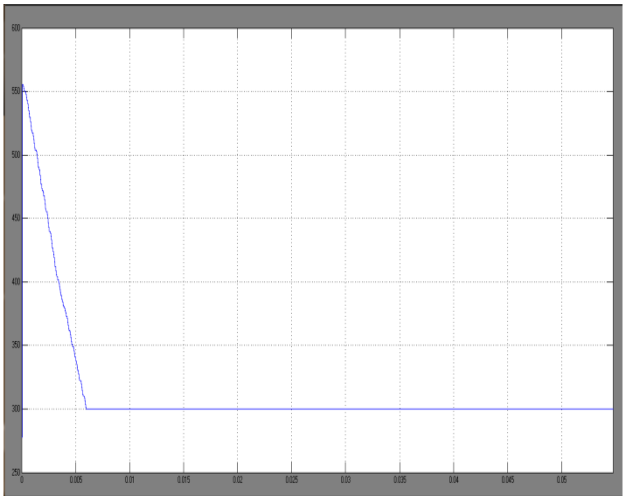

Fig.8 Converter Voltage

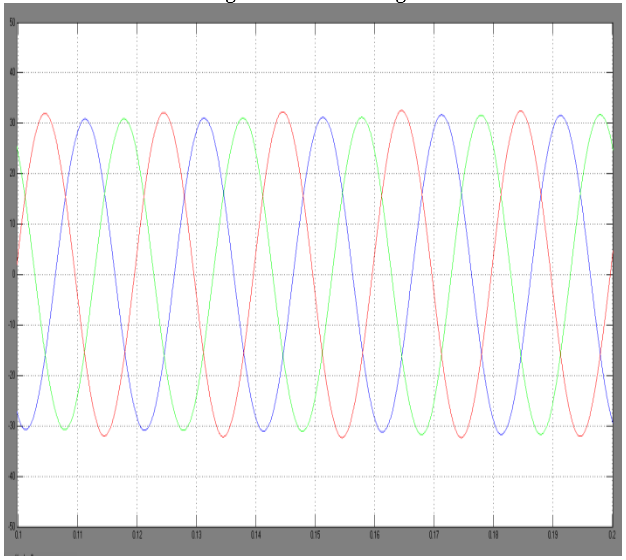

Fig.5 Three-phase stator currents

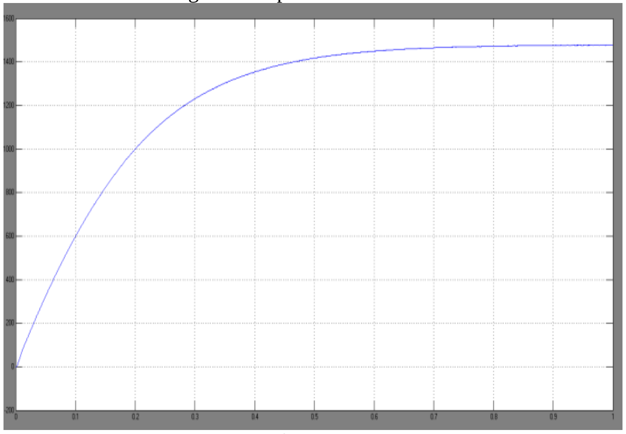

Fig.6 Speed of the Induction Motor

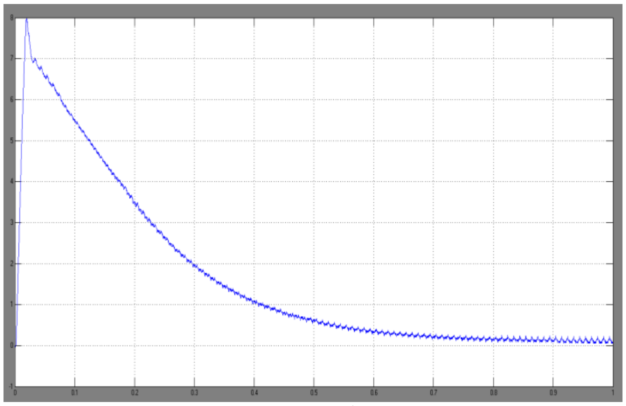

Fig.7 Torque characteristics of the Induction Motor

V. CONCLUSION

In this paper Interline Dynamic Voltage Restorer (IDVR) is used to overcome the voltage sag and swell with the use of hybrid multilevel inverter is presented to improve the Power Quality. This is proved by MATLAB simulation results. The result indicates that the load voltage is improved within few seconds using IDVR when faults or any disturbance occur in distribution system which shows the DVR‟s excellent performance and the control system in order to protect sensitive equipment from PQ disturbances. This proposed method is tested theoretically only however, exact practical testing is left. The effect of harmonics in induction motor and voltage drop due to connection of IDVR are to be tested.

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