Technique to Mitigate Inrush Current of Load Transformer by Series Voltage Sag Compensator

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Abstract - In power systems Survey results recommend that, voltage sag is the major contributor in about 92% of industrial installations. Voltage sag results in decrease in efficiency of the systems which affect the manufacturers in terms of losses related to money and credibility. The voltage sag compensator, a transformer-coupled arrangement associated voltage-source inverter, is among the most savvy arrangement against voltage sags. Transformers are often installed in front of critical loads for electrical isolation purposes. When voltage sag occurs, the transformers are presented to the improper voltages and a dc offset in its flux linkage. When the compensator restores the load voltage, the flux linkage will be reach to the level of magnetic saturation and this cause's serious inrush current. The compensator may be interrupted because of its own over current protection, hence, the compensation gets failed, and the critical loads are interrupted by the voltage sag. This paper introduces a technique for inrush current relief for voltage sag compensator.

Keywords — Flux linkage, Inrush currents, Transformer, Voltage Sag, Voltage Sag Compensator.

I. INTRODUCTION

Now a days there is large increase in load demand as the improvement of technology is changing day by day. With the change in load Condition the power quality is issue must also be taken into consideration. Due to the sudden change in the load i.e., sudden increase of load the magnitude of the current in the distribution system is increased rapidly which leads to decrease in the voltage of the line creating voltage sag.

There are three negative side effects of inrush currents:
1) Mis-operation of protective devices for overloads and internal faults may and disconnect the transformer.
2) The windings are exposed to mechanical stresses that can damage the transformer; and
3) Power-quality problems may occurs and voltage sags.

Various transformer inrush reduction techniques have been presented, like controlling power-on angle and the voltage magnitude, or actively controlling the transformer current. These methods are not suitable for voltage sag compensators as they could alter the output voltage waveforms of the converter.

The voltage sag means that the root mean square value of fundamental voltage temporarily reduces to 0.1~0.9 per unit and maintains 0.5 to 30 cycle. Hence, the load transformer is presented to the improper voltages before the restoration and magnetic flux deviation may be developed within the load transformers. Saturation of the core leads to significant inrush current. The compensator may be interrupted because of its own over current protection, hence, the compensation gets failed, and the critical loads are interrupted by the voltage sag.

In this paper, an inrush mitigation technique is presented. This control can successfully reduce inrush current of load transformers.

II. LITERATURE SURVEY

In the Literature survey it reveals that voltage sag is a critical problem in power system. Many inrush mitigation techniques have been presented by various researchers like controlling power-on angle and the voltage magnitude [1-5], or actively controlling the transformer current [6-8]. These methods could easily alter the output voltage waveforms of the converter, and thus, is not suitable for voltage sag compensators, which demand precise point-on wave restoration of the load voltages.

The repeated switching of distribution transformers take place due to poor generation and load shedding. The transient inrush current may be as high as ten times the full-load current. Three methods are given here to avoid inrush currents in transformers and distributed lines:

1. The switching instant decides the nature and magnitude of the switching current and it is used here to control the inrush current.
2. Another method is adopted by placing a capacitor at the secondary side of the unloaded transformer connected at the sending or receiving end of the distribution line.
3. Third method is proposed using the distribution line as a low-pass filter.

These schemes are useful for traction transformers as well as for poorly supplied and poorly maintained distribution lines including traction line which are subjected to repeat switching [1]. A new, simple and low cost method to reduce inrush currents caused by transformer energization. The method uses a grounding resistor connected at a transformer neutral point. By energizing each phase of the transformer in sequence, the neutral resistor behaves as a series-inserted resistor and thereby significantly reduces the energization inrush currents. The presented method is much less expensive, however, since there is only one resistor involved and the resistor carries only a small neutral current in steady-state [2]. A sequential phase energization based inrush current reduction scheme. The scheme connects a resistor at the transformer neutral point and energizes each phase of the transformer in sequence. It was found that the voltage across the breaker to be closed has a significant impact on the inrush current magnitude. In this paper it is shown that the idea of sequential phase energization leads to a new class of techniques for limiting switching transients [3]. The magnetizing inrush current which occurs at the time of energization of a transformer is due to temporary over fluxing in the transformer core. Its magnitude mainly depends on switching parameters such as the resistance of the primary winding, the point-on-voltage wave (switching angle), and the remnant flux density of the transformer at the instant of energization [4].

The authors in [5] have proposed a method which removes the need for rating the series injection transformers for the DVR transient switch-on period, and therefore removes the redundancy normally associated with their steady state operation. During the transient period at the start of voltage sag, a DVR injection transformer can experience a flux-linkage that is up to twice its nominal steady-state value. This paper [8] proposed a novel method of suppressing the inrush current of transformers. A small rated voltage source PWM converter was connected in series to a transformer through a matching transformer.

III. SYSTEM DESCRIPTION

As shown in Fig. 1, the voltage sag compensator consists of a three-phase voltage-source inverter (VSI) and a coupling transformer for serial connection. When the grid is normal, the compensator is bypassed by the thyristors for high operating efficiency. When voltage sags occur, the voltage sag compensator injects the required compensation voltage through the coupling transformer to protect critical loads from being interrupted. However, certain detection time (typically within 4.0 ms) is required by the sag compensator controller to identify the sag event [19]–[21]. And the load transformer is exposed to the deformed voltage from the sag occurrence to the moment when the compensator restores the load voltage. The magnetic saturation may easily occur when the compensator restores the load voltage, and thus, results in the inrush current. The inrush current could trigger the overcurrent protection of the compensator and lead to compensation failure. Thus, this paper introduces an inrush mitigation technique by correcting the flux linkage offsets of the load transformer.

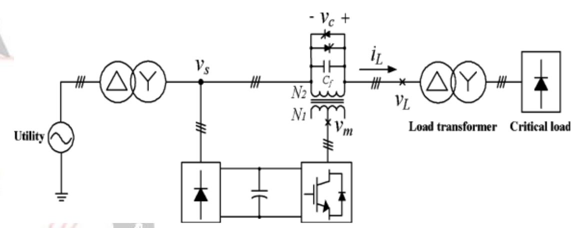

Fig.1 Simplified one-line diagram of the offline series voltage sag compensator.

Dynamics of the Sag Compensator -The dynamics of the sag compensator can be represented by an equivalent circuit in Fig. 2. Generally, the sag compensator is rated for compensating all three-phase voltages down to 50% of nominal grid voltage. The coupling transformer is capable of electrical isolation or boosting the compensation voltage inductor of the coupling transformer is used as the filter inductor Lf and is combined with the filter capacitor Cf installed in the secondary winding of the coupling transformer to suppress pulse width modulated (PWM) ripples of the inverter output voltage vm. The dynamics equations are expressed as follows:

$$L_f \frac{d}{dt}\begin{bmatrix} i_{ma} \\ i_{mb} \\ i_{mc} \end{bmatrix} = \begin{bmatrix} v_{ma} \\ v_{mb} \\ v_{mc} \end{bmatrix} - \begin{bmatrix} v_{ca} \\ v_{cb} \\ v_{cc} \end{bmatrix} \quad (1)$$

$$C_f \frac{d}{dt}\begin{bmatrix} v_{ca} \\ v_{cb} \\ v_{cc} \end{bmatrix} = \begin{bmatrix} i_{ma} \\ i_{mb} \\ i_{mc} \end{bmatrix} - \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad (2)$$

Where, [vma vmb vmc]T is the inverter output voltage, [ima imb imc]T is the filter inductor current, [vca vcb vcc]T is

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the compensation voltage, and [iLa iLb iLc]T is the load current. Equations (1) and (2) are transformed into the synchronous reference frame as the following:

$$\frac{d}{dt}\begin{bmatrix} i^e_{mq} \\ i^e_{md} \end{bmatrix} = \begin{bmatrix} 0 & -\omega \\ \omega & 0 \end{bmatrix}\begin{bmatrix} i^e_{mq} \\ i^e_{md} \end{bmatrix} + \frac{1}{L_f}\begin{bmatrix} v^e_{mq} \\ v^e_{md} \end{bmatrix} - \frac{1}{L_f}\begin{bmatrix} v^e_{cq} \\ v^e_{cd} \end{bmatrix} \tag{3}$$

$$\frac{d}{dt}\begin{bmatrix} v^e_{cq} \\ v^e_{cd} \end{bmatrix} = \begin{bmatrix} 0 & -\omega \\ \omega & 0 \end{bmatrix}\begin{bmatrix} v^e_{cq} \\ v^e_{cd} \end{bmatrix} + \frac{1}{C_f}\begin{bmatrix} i^e_{mq} \\ i^e_{md} \end{bmatrix} - \frac{1}{C_f}\begin{bmatrix} i^e_{Lq} \\ i^e_{Ld} \end{bmatrix} \tag{4}$$

where superscript ―e‖ indicates the synchronous reference frame representation of this variable and ω is the angular frequency of the utility grid. Equations (3) and (4) show the cross-coupling terms between the compensation voltage and the filter inductor current.

IV .METHODOLOGY

Voltage and Current Closed-Loop Controls- Fig. 2 shows the block diagram of the proposed control method. The d-axis controller is not shown for simplicity. The block diagram consists of the full state-feedback controller and the proposed inrush current mitigation technique.

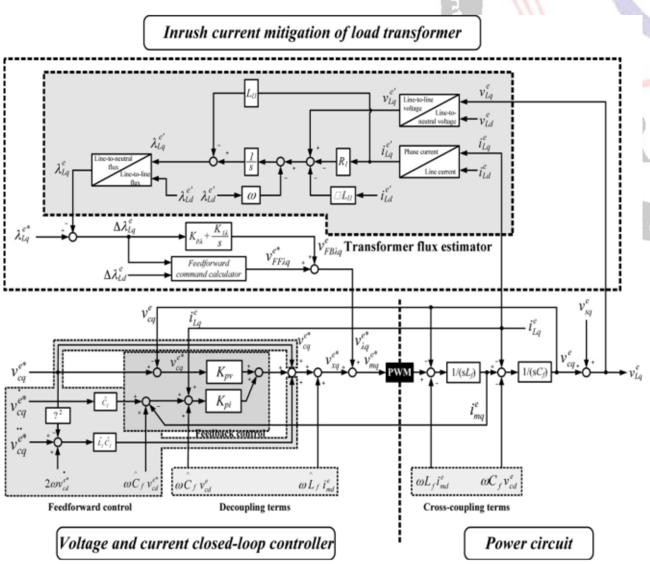

Fig.2 Block diagram of the proposed inrush current mitigation technique with the state-feedback control.

The feedback control, feed forward control, and decoupling control are explained as follows.

1) Feedback Control: The feedback control is to improve the precision of the compensation voltage, the disturbance rejection capability, and the robustness against parameter variations. As shown in Fig. 2, the capacitor voltage $vcq\ e$ and the inductor current $imq\ e$ are handled by the outer-loop voltage control and the inner-loop current control, respectively. The voltage control is implemented by a proportional gain Kpv with a voltage command $vcq\ e\ *$ produced by the voltage sag compensation scheme. The current control also consists of a proportional control gain Kpi to accomplish fast current tracking.

2) Feedforward Control: To improve the dynamic response of the voltage sag compensator, the feedforward control is added to the voltage controller to compensate the load voltage immediately when voltage sag occurs. The feedforward voltage command can be calculated by combining the compensation voltage and the voltage drop across the filter inductor Lf .

3) Decoupling Control: The cross-coupling terms are the result of the synchronous reference frame transformation, as in (3) and (4). The controller utilizes the decoupling terms to negate the cross coupling andreduce the nterferences between the d–q axes. Fig. 2 shows that the decoupling terms can be accomplished by the filter capacitor voltage $vcqe$ the filter inductor current $imq\ e$, and the estimated values of the filter capacitor and the filter inductor.

V .CONCLUSION

An inrush current mitigation technique based on the flux linkage close-loop control has been presented for the sag compensator system in this paper. This synchronous reference frame-based method can precisely estimate the flux linkage deviation introduced by the deformed sag voltages within the load transformer, and calculate the required voltage for correcting such deviation in real time. Thus, the risk of inrush current of the load transformer can be successfully avoided as the flux linkage deviation is neutralized once the sag compensator engages. The presented method utilizes the existing voltage and current sensor signals, and thus, it can be easily integrated with the voltage and current control of the sag compensator. The another method for controlling voltage sag and flux saturation in transformers used by a DVR system which uses fuzzy logic controller to compute the compensating voltage. This ensures that the compensating voltage is always at a proper level.

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