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MSRF Control Based Interline Dynamic Voltage Restoration in Distribution Line

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Abstract*: This paper deals with the implementation of interline dynamic voltage restorer (IDVR) system using three-phase inverter integrated with PLL based MSRF controller for regulating the DC link voltage, and reducing the voltage sag. Voltage variation that frequently occurs either in the form of voltage sag or swells and it can cause major damage to the environment and distribution station. In this paper, interline dynamic voltage restorer has proposed which consist of more than one DVR's are commonly connected with the DC link capacitor of the system. Suitable control methods are developed for reduce the voltage sag in the line. Modified synchronous reference frame control has designed and implemented for both controls, and compensation of voltage sag. Conventional control method has some constraints such as high settling time of dc link voltage, and increase in harmonics that could be overcome by a new approach of MSRF based PLL has presented in this paper, which helps to compensate the voltage sag occurs in the system. Furthermore design and analysis of MSRF based IDVR is proposed to improve the efficiency, reducing the settling time of DC link voltage, reducing the harmonics distortion, and minimize the power quality issues by using MATLAB/SIMULINK.

Keywords: DC link, Interline Dynamic Voltage Restorer (IDVR), Modified Synchronous Reference Frame Controller (MSRF), Voltage Sag.

I. INTRODUCTION

The main significance of the electrical distribution system is to delivers the power to the customer through the transmission line without any losses. Distribution of electric power is transferred from grid-connected source to different applications and appliances. Power quality and power losses are widely considered due to its rigorous impact on sensitive loads in industries, medical tools and various effects on the power system. Due to the constraint of environment and economy, the power system is operated closer to their stability limits, so there is a need to the protection of generation, distribution, and transmission of the system from the losses. During non-linear load condition, the conventional methods are used for compensation of voltage sag and which gives ineffectual performance. Decrease in RMS voltage value with short duration fault longer than 1 min is defined as voltage sag or drop and sudden increase in RMS voltage value with a short period of fault longer than 1 min is called voltage swell [1]. Voltages swell/sag affects in a distributed system and it cause reduction of voltage and mitigation of power quality. Disconnections of load lead to immediate reductions in current, which will give increase the voltage. Voltage swell causes severe damage to electrical equipment and overheat. The most frequently occurring three-phase fault is become one of the foremost troubles which effect in voltage sag and swell so that the researchers and developers are designed the various devices on to control and reduces the losses till the end of the customer. Distribution side power quality issues are to reduce by using the power electronics devices. Different types of power electronics devices are used for improve the voltage compensation and power quality issues such as Static Var Compensator, Static Synchronous Compensator, Thyristor Controlled Series Compensator, Interline power Quality Conditioner or Improved Power Quality Conditioner, Thyristor Protected Series Compensation, Unified Power Flow Controller, Unified Power Quality Conditioner [2] [3], and Dynamic Voltage Restorer. The custom power electronic devices are playing an important role in distribution side during impairments, voltage disturbances such as voltage sag and voltage swell, voltage spikes, harmonic distortions.

One of the custom power devices has dynamic voltage restorer, and it is connected series with the supply voltage to control the load side demand in feeders. It can be used to overcome the problems of power quality issues, unbalanced supply voltage and harmonic distortion [13]. DVR helps to maintain the injection of reactive power from the source [4]. The function of DVR depends on the amount of voltage injected from the inverter and common dc link. The main objective of using DVR in distribution line as following: power losses in the network are to reduce, reduces the harmonic distortion and unbalance voltage in the system. Interline dynamic voltage restoration of distribution line where two or more than one DVR connected in series with supply for regulating the load voltage. Different feeders are connected to a common dc link capacitor in the system and to form an IDVR topology [5]. The function of IDVR is let consider the voltage swell or sag fault occurred in the feeder-1 in distribution line and another DVR in the feeder -2 is to compensate that power quality issue, and it refills the energy in the DC link [6, 8]. Loads are in independent of two feeders are protected from voltage sag by individual DVR in feeders.

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Generally, control systems are used in the power system for the control of power flow during the fault period and improve the power quality issues [9, 12]. There are many controller analysis and design on the development of suitable control methods for regulating the voltage sag.

This paper focused on the Modified Synchronous Reference Frame Theory (MSRF) based controller has been adopting for this series compensation. Modified SRF based controller which is analyzed for the benefit of voltage that occurs in the feeder of the distribution network. In this paper analyzing the performance of modified synchronous reference frame based controller on interline dynamic voltage restorer is proposed, reducing the harmonics distortion, and improving the performance of feeders in the distribution network by using MATLAB/Simulink tool.

II. OBJECTIVE

The main objective of this presented paper is to regulate the DC link voltage which is connected between two different feeder lines, and compensating the voltage sag occurred in the transmission feeder line that can be minimized by implementing an inter-line dynamic voltage restorer with PLL based MSRF based controller.

III. PROPOSED METHODS AND MATERIALS

The proposed development consists of two different feeders (400V and 200V), load, transformers, DVR's connected between the feeders, and PLL based modified reference frame controller. Proposed diagram of the IDVR is shown in figure 1. In feeder-1, input voltage fed to the load through the transformer without any issues like voltage sag. Voltage sag is occurred in feeder-2 due to 25% of fault that can be compensated by DVR in feeder-1. During this period feeder-1 inverter acts as a rectifier. The rectified voltages send to the inverter which is connected with feeder-2. An inverter can be performed by implement of modified reference frame controller that gives pulse to the inverter switches to converts the DC voltage into AC voltage.

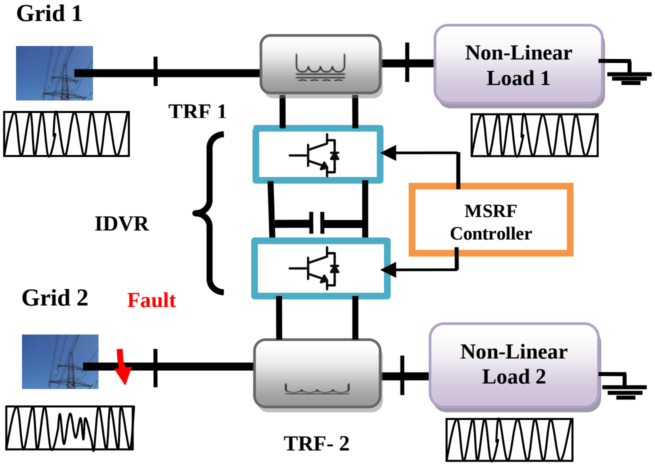

Fig. 1.Voltage compensation using MSRF controller based two-line dynamic voltage restorer

A. Three Phase Voltage Source Inverter (VSI)

Reduction of voltage sag in IDVR system uses the 3ϕ voltage source inverter system which has 6 switches shown in figure 2, namely Sa, Sb, Sc, Sd, Se, and Sf. In that Sa, Sc, Se is upper leg switches and Sb, Sd, Sf is lower leg switches. In feeder-1 3ϕ inverter in DVR-1acts as a rectifier and feeder-2 DVR act as an inverter. PLL based MSRF with pulse width modulation (PWM) generates the switching pulse to that inverter, which injects the amount voltage to be used for compensates the voltage sag feeder-2. At that time DC link capacitor replenishes energy to the transmission line-1. In case of voltage sag will take place in transmission line-1 after the time of voltage sag compensation of transmission-2. It repeats the same process to the transmission line-1 that time inverter in feeder-2 acts as rectifier. Otherwise remaining process is same.

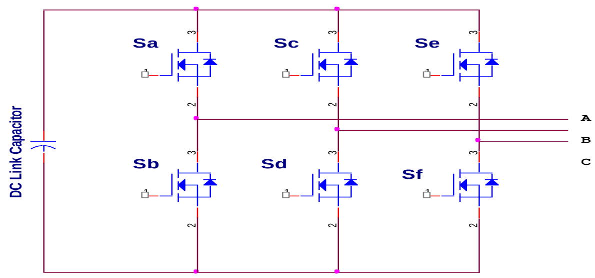

Fig. 2.Schematic representation of 3ϕ VSI circuit voltage restorer

B. Injecting Transformer (VSI)

Generally, in power system application, transformers are utilized for injecting the voltage at fault section. Due to this voltage injection operation of the transformer, compensate the voltage sag in the source side of feeder-2. Voltage sags are sensed by the breaker and real power transferred to the feeder-2 through transformer-2 by boosting technique/step up. A 250V, three 1ϕ transformers are used for supplying the power to the load.

C. DC Link

Converters are linked between the two different transmission line formed the DC bus is called a common DC link. "DC link" is also suggested as a decoupling capacitor. It is connected between rectifier side of feeder-1 in transmission line-1and inverter side of feeder-2 in transmission line-2. The main purpose of this capacitor is to replenish (energy can use again) the energy to the overall network is shown in figure 3. DC link capacitor is utilized for protecting the system, and it reduces the addition of voltage source.

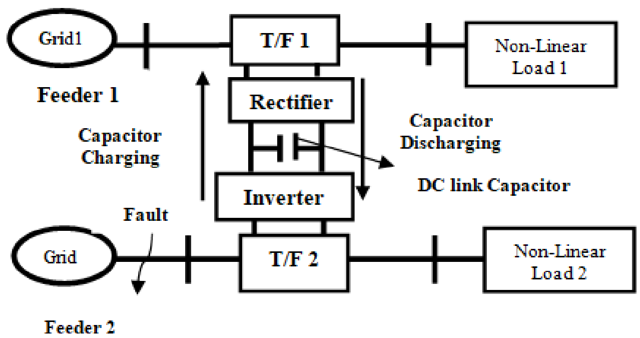

Fig. 3. Charging &discharging of common DC link capacitor

D. Passive Filter

Due to the connection of non-linear load in receiving end causes the voltage sag, which fluctuate the nominal voltage that may lead to the generation of harmonics in the system and that draws current from the source. Improve the responsibility of the system, and limits the THD in current by using filters. There are two types of filter used to reduce the harmonic in the system, namely, passive filter, and an active filter. In active filter, there is a need for additional source to minimize the current ripples in the system, but in the passive, there is no need for additional sources. It is the combination of passive electronic components such as inductor, capacitor, and resistor. Single tuned filter represent in figure 4 (Inductor-Capacitor filter LC) is preferred to minimizing the harmonics [13, 14] in the line.

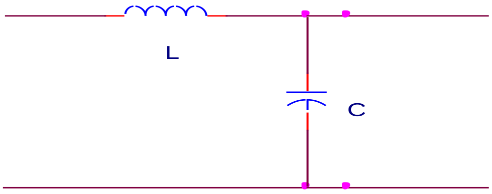

Fig. 4.Single tuned filters (LC) circuit

IV. CONTROL METHODS

Provide Control methods of IDVR are two types: voltage compensation mode (discharging) and replenishing (charging) mode. The whole function can be controlled by the method of modified synchronous reference frame controller as represented in figure 5. The control method utilized for extracting the essential elements of source voltage and source current is called a modified synchronous reference frame theory and its version of a typical synchronous reference frame method. PLL is used to calculate the voltage and phase angle, which is used to generating the reference for the MSRF controller.

A. Theory of MSRF and Generation of Reference Voltage

The function of this MSRF method is shifting the frequency (δ) and transforms the frequency of the phase lock loop in DC at the same time other element keeping as AC. During this time of transformation, the signal is generated, and the resulting signal passes through the filter. This method consists of orthogonal signal (sinωt, cosωt) produced by the PLL block. After the generation of source current and voltage, the phase difference between two orthogonal signals is detected, calculated, and compared with a reference phase difference. The control signal (C) is produced by PI, related to the PWM generator that shifts the source waveform. After that power is flowing through converter, and it charges/discharges the DC link. DC link voltage is not constant because the compensation range of DVR can oscillates the DC link. By the method of MSRF Harmonics current in the converter is separate from the fundamental element. Real power flow can be represented in below equation along with phase shift (δ),

$$Vsource.Vcompensate / X \sin(\delta) \qquad (1)$$

The required amount of voltage that should be injected /drawn by the DVR, and it depends on how much voltage is to be required for compensating the demanded by the load. There are many algorithms, control techniques and theories are used to establish the real and reactive power in the power system. MSRF [10] theory-based control method is utilized for producing a reference signal for the switching of three-phase inverter in DVR.

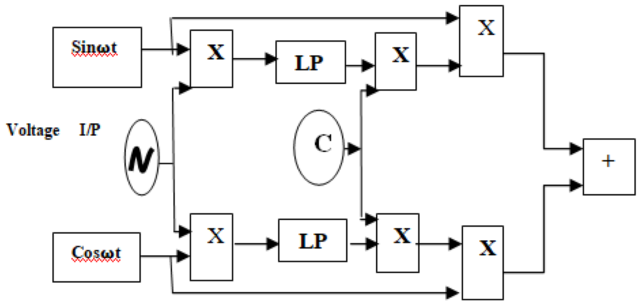

Fig. 5.Modified reference frame based controller

V. SIMULATION RESULTS

In order to verify the function of interline dynamic voltage restorer using PLL based modified reference frame controller of figure 6, simulation model has been designed by Matlab/Simulink. It is carried out to verify the efficiency of the presented IDVR to mitigate the long period voltage sag at the time of 0.2s-0.35s. Test parameters of the presented system are given the below table, and it consists of two transmission line of 1.9KV and 150V. Source impedances of the line are chosen depending on the occurrence of the fault. From the results of presented simulation consider as that the feeder line-2 is subjected to the 3ϕ voltage sag of 25% at that time feeder line-1 is operated at normal operation condition. Parameters values are tabulated in below table 1.

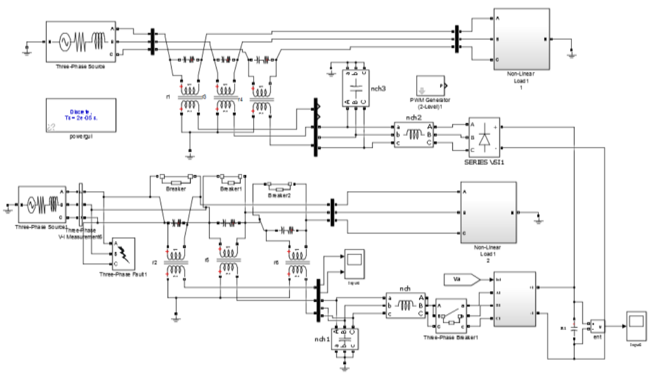

Fig. 6.Simulation diagram of the proposed modified synchronous reference frame theory based IDVR system

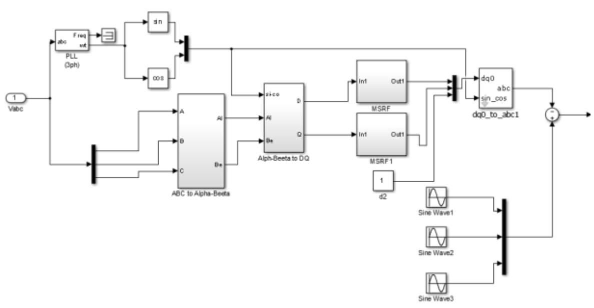

Fig. 7. Simulation PLL based MSRF controller

Grid voltage (V2abc) sends to the phase lock loop, and (Clark's) transformation it converts the V2abc into ɵ and α, β. This ɵ and α, β values are fed to αβ to dq transformation then modified synchronous reference frame filter after that transformation of dq to abc (Park's).

It produces the pulse to the switches in inverter. Overall setup represented in figure 7.

Output voltage of feeder-1 is 400V and it represents in figure 8.

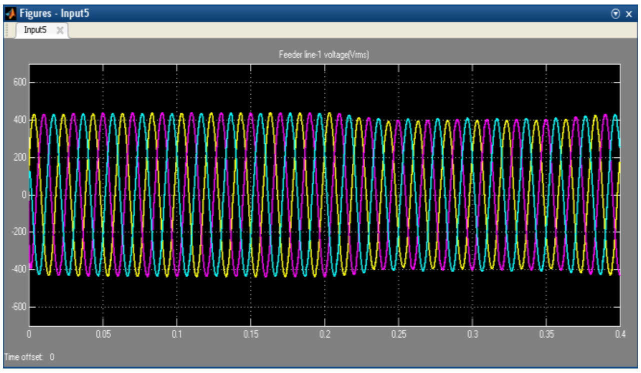

Fig. 8. Feeder-1 voltages

Output voltage of feeder 2 is represented in figure 9 which has 200V with 25% of voltage sag at the time of 0.2s-0.35s. Voltage sag could be compensated by DVR in feeder-2 compensated output voltage show in figure 10 voltage injected from the feeder-1 is show in figure 11. This voltage doesn't affect the remaining feeders in the network; it lags the source feeder-1 and leads the receiving feeder-2. DC link voltage and %THD value of feeder- 2 has 5.63% using LC filter are represented figure 12, 13.

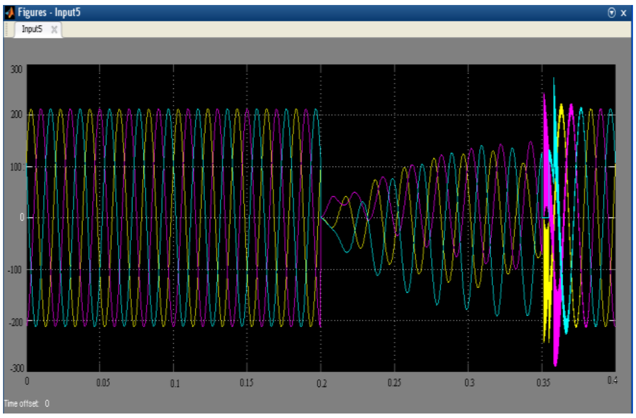

Fig. 9.Feeder line-2 voltages with voltage sag

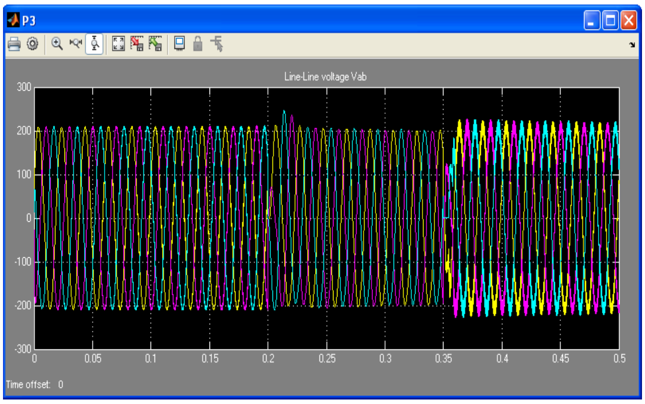

Fig. 10. Compensated voltage at feeder line-2

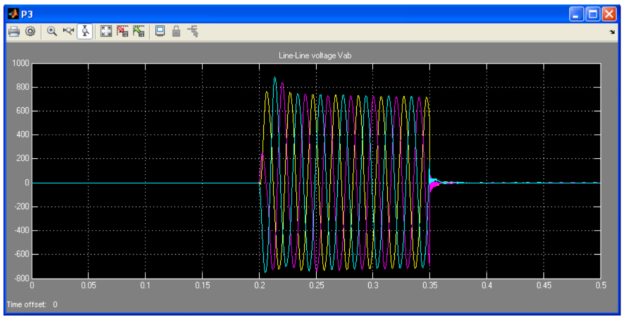

Fig. 11. Injected voltage

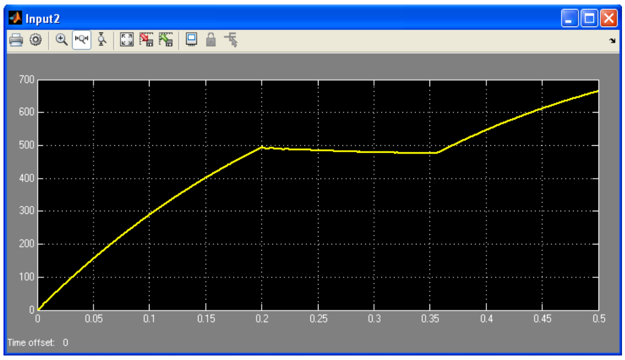

Fig. 12. DC link voltage

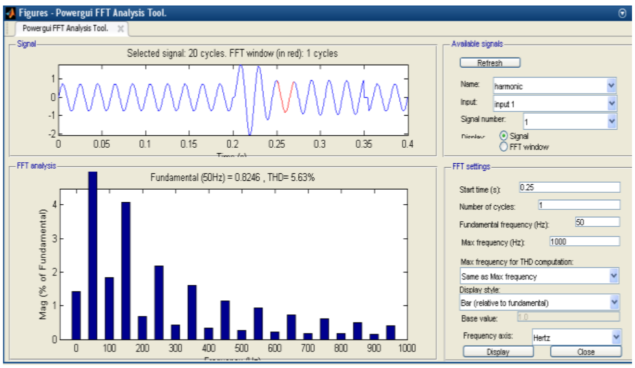

Fig. 13. THD of output current in feeder 2

Table- I: Parameters values

S.NO	Parameter	Ranges
1.	Input voltage (feeder 1& feeder 2)	1.9KV & 150V
2.	LC filter	L=100 μ H,C=160 μ F
3.	DC link capacitor	450 μ F

VI. CONCLUSION

The concept and implementation of IDVR which is the cost-effective method, to improve the quality of power, reducing the settling time of dc link voltage, and mitigate/compensate the voltage sag in feeders using PLL based MSRF controller has proposed in this paper. In this paper, two DVR's are connected to the common DC link, and one of the DVR compensates the voltage sag/swell another one performing the voltage replenish process by DC link capacitor has analysis and implemented.

MSRF based PLL controller is designed and controls the process of IDVR setup, and it has connected with a non-linear load. When applying this interline dynamic voltage restorer satisfy some constraints such as long-period voltage sags, and unbalance voltage.

The overall setup has implemented using MATLAB/Simulink. The presented topology has designed for reducing the harmonics in the system, compensates the voltage sag of 25%, reducing the settling time of the dc link voltage, cost-effective method, and efficiency.

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