VOLTAGE CONTROL FOR THREE- PHASE INVERTER BASED DISTRIBUTED GENERATION UNDER GRID DISTURBANCES

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ABSTRACT

The recent trend of distributed generation leads to several issues regarding power quality and energy efficiency. To meet the increased demand of electricity services and to increase service quality the current power grid structure should be controlled in such a way that distributed generation could be easily connected to it. The various services are becoming challenging concern to elegantly integrate distribute generation to the grid. One of these services is voltage control which provides support to the voltage under grid fault conditions. During voltage sag condition continues power supply should be provided to grid. According to grid code requirement of transmission system, several kind of voltage sag requires different voltage control strategies. Hence in this paper a flexible control strategy for three phase grid connected inverter is proposed. The inverter should be controlled in such way that it should inject reactive power in case of three phase balanced voltage sag condition in order to raise voltage in all three phases. In case of single line to ground fault, double line to ground fault condition and in several fault condition the main aim of inverter is to balance the voltages. The proposed inverter balances the voltages by sinking negative sequence components during this fault conditions. Thus the proposed control strategy avoids discontinuation of supply while accomplishing the chosen voltage support service so that voltage dips and voltage swell can be avoided. And this can be investigated and simulated by using Matlab/Simulink. This paper proposes a new control algorithm for the generation of the reference current which offers voltage provision in case of grid disturbances.

Keywords: grid fault, distributed energy resources, inverter based distributed generation, voltage sag, voltage control.

INTRODUCTION

The growing trend of use for renewable energy sources (RES) is continuously increasing in last few decades. When these RES are connected to the grid they act as distributed generation systems [1]. Usually, in case of fault when there is disturbances occur DG's are required to disconnect from the grid. As soon as faults are cleared it is reconnected to the grid But in case when number of distributed generation systems are required reconnect to the grid, there comes problem of instability[2]. One of the main issue which is caused by the disturbances is the voltage sag. Voltage sag is the decrease in the rms value of voltage. In actual scenario most of the voltage sags occurs due to unbalanced faults such one phase to ground fault, two phase to ground fault and etc. whereas balanced voltage sags are comparatively unusual in practice. To standardize the behavior of grid connected distributed generation (DG) sources at normal condition and at unbalanced voltage sag condition, some international standards and national grid codes are provided [3]-[5]. According to the grid code necessities in case of voltage sag conditions, there are mainly are two basic grid codes. One of those is to achieve unceasing process setting of the voltages at the point of common coupling (PCC) between boundaries and the other is to fix the quantity of reactive power injection. To hold the grid voltage resistant to unstable faulty condition the voltage support can be achieved by using power quality compensation devices [10]. The main device for intersecting distributed generation to grid is three phase inverter [21]. Regarding with control of inverters in case of unbalanced voltage sag condition voltage dips, two facts should be noted. The first one is the fast dynamic response of the system and the second one is fine reference tracing strategy. In the case of normal operating grid conditions, three phase inverters try to inoculate generated active power into transmission grid. There are certain limitations regarding connection of inverters to the grid, to cope up with these limitations a flexible voltage support control scheme is provided [11].This control scheme allows recovery positive sequence voltage as well as deduction of negative sequence voltage. But the most important disadvantage for correct working of entire system arises when voltage dip is transferred over the network. The controller should respond to the disconcertion and to diminish the hostile effects on the inverter side at the case of the fault on the grid [20]. In this paper a novel control algorithm is presented to counteract with problem of various kinds of voltage sags. Each and every time when there balanced three phase voltage sag takes place, the proposed voltage control strategy should require to increase the voltage in remaining phases. A voltage balancing scheme should come in the act only when one or two phase fault condition occurs. Voltage balancing is achieved only when there is difference between rms voltages is decreased. So it is possible to avoid overvoltage and under voltage. Additionally negative sequence component of voltage gets decreased as well as sudden increase in the phases are cleared. These are the main operations for correct working of the distributed generation inverters [12]. To evade discontinuation, phase voltages should lie within limits. Growing trend of penetration of DG into the grid requires novel control. The control algorithms with greater performance are required to increase reliability of grid as well as to improve efficiency of grid. This is the basic thing which is required for proper working of the Distributed Generation DG system.

Voltage sag in power system

Voltage sag is a per unit decrease in rms value of the supply voltage. If the voltage reduces below the nominal voltage with 90 percent amount, it is called voltage sag. It is only in temporary in nature not the complete disruption of power. Voltage sags are becoming more important power quality issue in which industrial customers are facing today. And it can become most significant difficulty for big commercial consumers also. There are mainly two sources of voltage sags. One is external and other is internal. Lightning strokes, temporary interruptions, single phase to ground fault, short circuit of phases and storms are the more frequent source of external sags. Sudden increase or decrease in loads and starting of motors are the cause of internal voltage sags. Depending on the magnitude, duration of the voltage sag and sensitivity of equipment, severity of the voltage sag can be evaluated. The sensitive electronic equipment's are such as variable speed drive (VSD) controls, programmable logic controllers (PLC's), motor starter, power supply controller etc.

Voltage Sag Classification and Characterization

In the grid system, voltage sag is considered as an abnormal condition. And they are significant reduction in one or several phases for a very short time. There are several classification methods. One of those is according to magnitude and phase angle jumps [17]. There are several types but following four are the basic types like Type A, B, C and D [16].

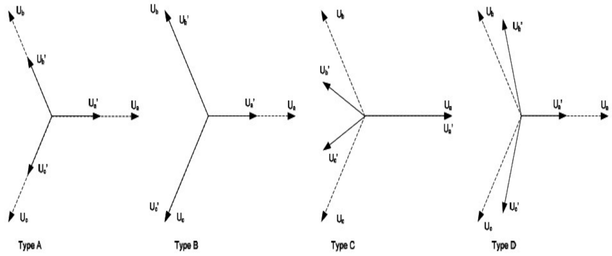

Figure-1. Voltage sag type A, B, C and D.

According several authors the voltage sag of types B,C and D produces positive and negative sequence voltage which distorts the current and affects the power quality of grid[12].

This voltage sags are also characterized the positive, negative, and zero symmetric sequences:

$$v_a = v_a^+ + v_a^- + v_a^0 \tag{1}$$

$$v_b = v_b^+ + v_b^- + v_b^0 \tag{2}$$

$$v_c = v_c^+ + v_c^- + v_c^0 \tag{3}$$

In the above equations the super scripts (+, - and 0) are called positive, negative and zero sequence symmetries. The Clarke transformation is applied to present the voltages in stationary reference frame theory.

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 2 & -1 & -1 \\ 0 & \sqrt{3} & -\sqrt{3} \end{bmatrix}\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{4}$$

Using the Clarke transformation the equations (1)-(3) can be represented in terms of positive, negative sequence components.

$$v_\alpha = v_\alpha^+ + v_\alpha^- \tag{5}$$

$$v_\beta = v_\beta^+ + v_\beta^- \tag{6}$$

The voltage unbalance factor (*n*) is a very important factor to characterize the voltage sag . It is the ratio amongst positive and negative voltage amplitudes. This parameter designates amount of imbalance in the system.

$$n = \frac{v^-}{v^+} = \frac{\sqrt{(v_\alpha^-)^2 + (v_\beta^-)^2}}{\sqrt{(v_\alpha^+)^2 + (v_\beta^-)^2}} \tag{7}$$

To evade failing problems due to imbalances the value of n should be $n < 0.02$ according to the standards [13].

Grid Connected Three Phase Inverter

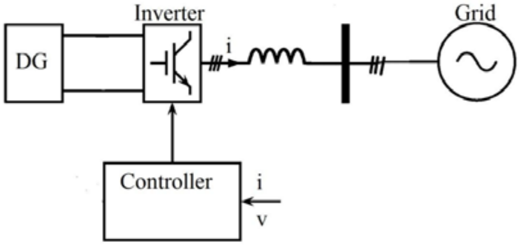

Figure-2. Single line diagram of the whole DG system.

The single line diagram of the whole system is as shown in Figure-2. This comprises DG source, inverter and the grid. The three phase voltage source inverter with the PWM switching strategy is used [15]. The inverter is connected to the grid via coupling inductor to reduce harmonics at the point of common coupling (PCC). Inverter and DG are interconnected with the Dc link. By controlling the DC link voltage, the power flow from DG cab be balanced. During fault on the transmission system, the voltage at the grid can be affected and hence the voltage pattern of the system gets distorted. To keep balanced voltages in the grid, the inverter must inject power into the grid.

Inverter Control Strategy

Injected current into the point of common coupling determines performance of the current mode of the inverter. In case of fault condition the voltage at the point of common coupling (PCC) is increased to maintain the balance in the grid by injection of the reactive power. Then after by using appropriate reference current generation technique voltage dip events and its effects in case of fault condition is minimized. The controller block diagram is as shown in the fig.3 [11].

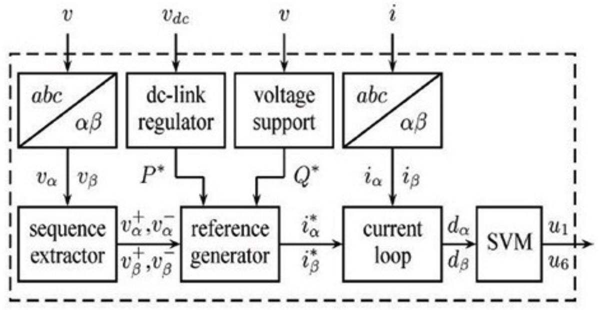

Figure-3. Block diagram of the controller [11].

The three phase voltages and currents at the point of common coupling are measured and this is given as input to the controller and also to the DC link regulator. Then these three phase voltages and currents are converted into stationary α-β values. Sequence extractor then transforms these values of voltages in the form symmetric components. To maintain the power flow into the grid the DC link voltage has been controlled by the DC link controller by using active power reference P. The voltage sag is detected by the voltage support control system using calculation in terms of rms values. The voltage support control comes into action whenever the rms value of the voltage reduces below a set point. The reactive power reference *Q** is generated by this block. The reference generator generates reference currents the i_α^* and i_β^* by using the data generated from the above blocks. To adaptably maintain the grid voltage, reference current generator is the main circuit for the control algorithm. According to the PCC currents and reference currents, the control loop works. To generate the switching pulses to the inverter the space vector pulse width modulation technique is used.

The main aim of control strategy is to demonstrate a process to ride through voltage sags and balance the voltage at grid. This control scheme should increase the voltage in all phases in case of balanced voltage dip. According to grid current, the controller should balance the voltage within suitable ranges in case of single and two phase fault condition.

Reactive Power Compensation

Reactive power is not used in AC electric network having unit Volt Ampere Reactive (VAR). But in the DC circuits it gets converted into heat, in case when energy storing elements are used across a resistor. Reactive power plays significant role in the AC electrical circuit as most of residential, commercial and industrial loads as well as power network operates on AC supply. The electrical power factor of any equipment determines the need of reactive power is determined by power factor (pf) of the apparatus [14]. The power factor of any equipment is the ratio of real power to the apparent power. Voltage in the system changes due to various reasons, it deteriorates the power quality. But subsequently consumers require good power quality. Hence it is required to control the voltage.

Proposed control strategy

The inverter abstracts the active power from the source and supplies to grid during balanced condition. For the real power (P) and reactive power reference currents are expressed as [14]:

$$i^*_{\alpha(P)} = \frac{2}{3} P^* \frac{v_\alpha}{(v_\alpha)^2 + (v_\beta)^2} \tag{8}$$

$$i^*_{\beta(P)} = \frac{2}{3} P^* \frac{v_\beta}{(v_\alpha)^2 + (v_\beta)^2} \qquad (8)$$

$$i^*_{\alpha(q)} = \frac{2}{3} Q^* \frac{v_\beta}{(v_\alpha)^2 + (v_\beta)^2} \tag{10}$$

$$i^*_{\beta(q)} = \frac{2}{3} Q^* \frac{-v_\alpha}{(v_\alpha)^2 + (v_\beta)^2} \tag{11}$$

Where the subscripts, P* is active power reference and Q* is reactive power reference.

In case of grid fault condition symmetric sequences of reactive current can be represented as:

$$i^*_{\alpha(q)} = \frac{2}{3} Q^* \frac{v_\beta^+ + v_\beta^-}{(v_\alpha^+ + v_\alpha^-)^2 + (v_\beta^+ + v_\beta^-)^2} \tag{12}$$

$$i^*_{\beta(q)} = \frac{2}{3} Q^* \frac{-v_\alpha^+ - v_\alpha^-}{(v_\alpha^+ + v_\alpha^-)^2 + (v_\beta^+ + v_\beta^-)^2} \tag{13}$$

Various results can be found by mixing positive sequence voltage as well as negative sequence voltage by the reference currents and application of this with reactive reference current results in various voltage support techniques and it is scrutinized by voltage support service [18],[19]. The voltage at the point of common coupling PCC is represented as:

$$v_\alpha = v_{g\alpha} + L_g \frac{di_\alpha}{dt} \tag{14}$$

$$v_{\beta} = v_{g\beta} + L_g \frac{di_{\beta}}{dt} \tag{15}$$

With the help of reactive current references given below the stability between positive sequence and negative sequence component is obtained to produce a proposed voltage support scheme. The subscripts used in (16) & (17) are k^{+} positive sequence and k^{-} negative sequence control parameters to raise the voltage under grid fault.

$$i_{\alpha}^{*}(q) = \frac{2}{3} Q^{*} \frac{k^{+} v_{\beta}^{+} + k^{-} v_{\beta}^{-}}{k^{+}[(v_{\alpha}^{+})^2 + (v_{\beta}^{+})^2] + k^{-}[(v_{\beta}^{+})^2 + (v_{\beta}^{-})^2]} \tag{16}$$

$$i_{\beta}^{*}(q) = \frac{2}{3} Q^{*} \frac{-k^{+} v_{\alpha}^{+} + k^{-} v_{\alpha}^{-}}{k^{+}[(v_{\alpha}^{+})^2 + (v_{\beta}^{+})^2] + k^{-}[(v_{\beta}^{+})^2 + (v_{\beta}^{-})^2]} \tag{17}$$

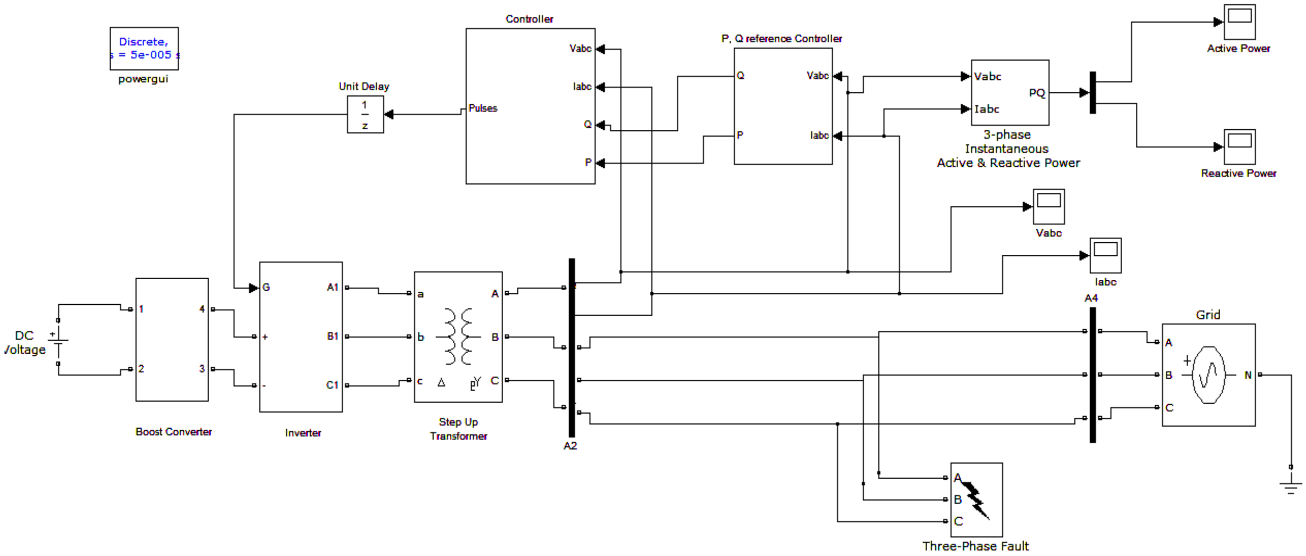

Figure-4. Complete Simulink model of the system with proposed controller and grid connected converter.

By standardizing the control parameters k^{+} and k^{-}, the following equation is obtained:

$$k^{-} = 1 - k^{+} \mid k^{+} \in [0,1] \tag{9}$$

The desired voltage support check is obtained by using particular value of *k*. By considering only positive sequence voltage active reference currents are given as:

$$i_{\alpha(p)}^{*} = \frac{2}{3} p^{*} \frac{v_{\alpha}^{+}}{(v_{\alpha}^{+})^2 + (v_{\beta}^{+})^2} \tag{19}$$

$$i_{\beta(p)}^{*} = \frac{2}{3} p^{*} \frac{v_{\beta}^{+}}{(v_{\alpha}^{+})^2 + (v_{\beta}^{+})^2} \tag{20}$$

The total sum of active and reactive currents gives complete reference currents.

$$i_{\alpha}^{*} = i_{\alpha(p)}^{*} + i_{\alpha(q)}^{*} \tag{21}$$

$$i_{\beta}^{*} = i_{\beta(p)}^{*} + i_{\beta(q)}^{*} \tag{22}$$

In this algorithm can be for fast and accurate fault detection is necessary in the system so that phase lock loop (PLL) can be used for system protection [22].

Space vector pulse-width modulation (SVPWM) is widely used current control scheme for three-phase voltage source inverters. In this theory an advanced SVPWM based current controller is stated and studied. This controller comprising deadbeat control with synchronous reference theory which is very simple and robust [24].

Simulation Results

To examine accuracy of the given the software tool MATLAB/Simulink is used. The performance of the proposed control strategy is simulated and the voltage sag evaluation is carried out. The novel control scheme which has proposed in this paper successfully recovers positive sequence voltage as well as reduces negative sequence voltage in the power system.

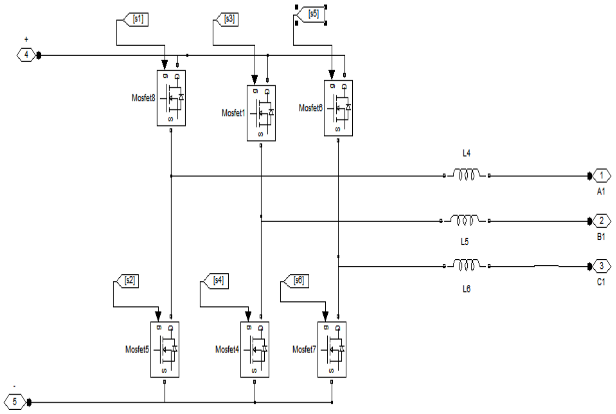

Figure-5. Three phase three leg inverter with the inductor filter.

The complete Simulink model of the given system is as shown in the Figure-4. And Figure-5 demonstrates the three phase three leg power inverter with the inductor filter.

Table-1. Main parameters of the power system.

DC nominal voltage	400 V
Filter Inductance	10 mH
Filter Capacitance	20 μF
IBDG Transformer rating	415 V/ 21KV
System frequency	50 Hz
Switching frequency	15 KHz
Grid Voltage	21 KV

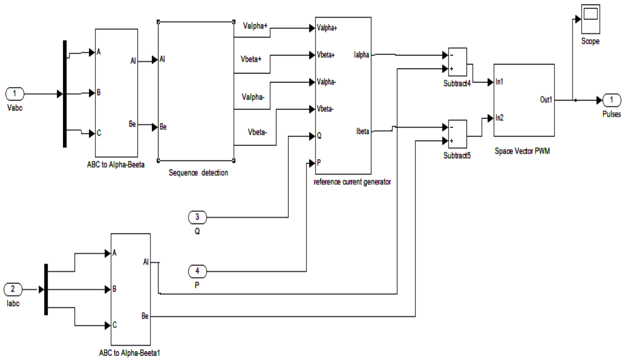

Figure-6. Simulink diagram of the proposed voltage control strategy.

The proposed voltage control scheme is shown in the Figure-6. In the given paper the controller is the main part that compensates the voltage sag. The evaluation is carried out under the single phase to ground fault, two phase to ground fault, three phase to ground fault and phase to phase to fault. Corresponding voltage and current output waveform for the same is shown in the Figure-7 and 8.

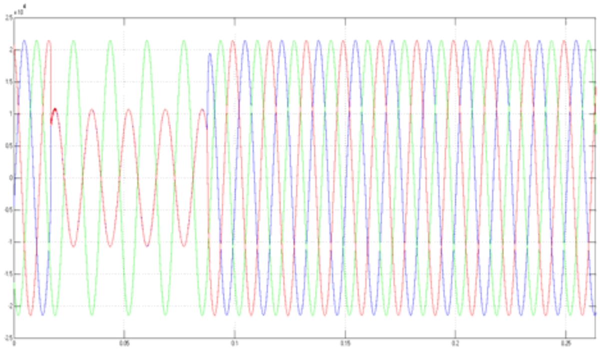

Figure-7. Three phase output voltage waveform under the fault condition.

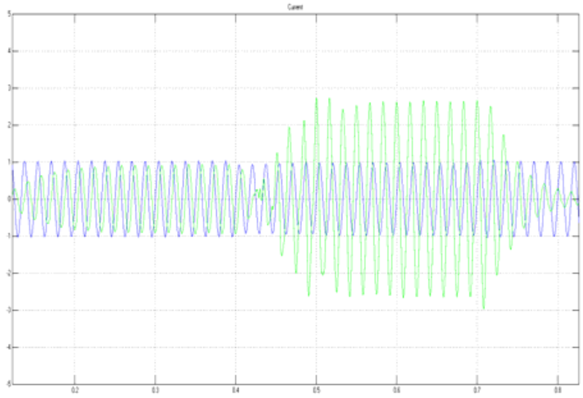

Figure-8. Current injected by the inverter under the fault conditions.

These waveforms shows the injected output current by the inverter due to the given control strategy so that the voltage sag can be mitigated. The injected active power is shown in Figure-9. And the compensated reactive power is as shown in Figure-10.

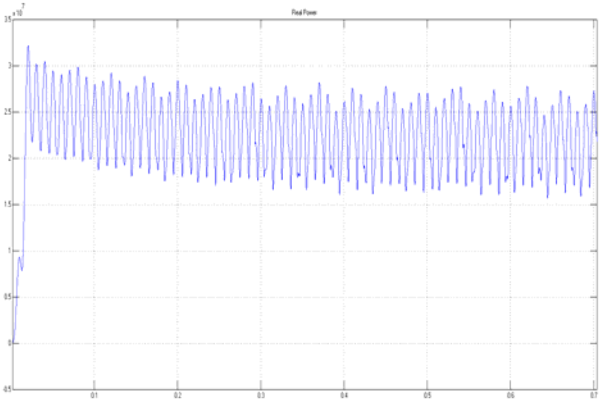

Figure-9. Real power supplied by inverter.

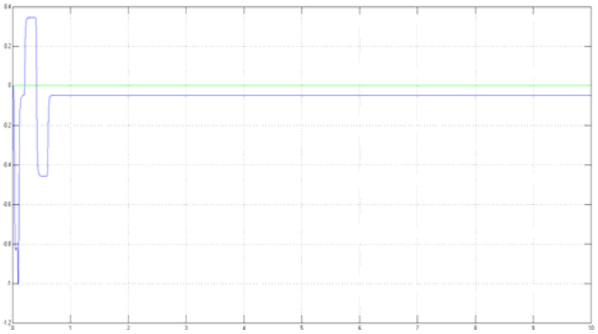

Figure-10. Actual and reference reactive power.

It can be seen from the simulated output, large power oscillations unbalances in the voltage are reduced. Hence the control parameter value can be properly chosen for practical considerations. The proposed novel voltage control scheme effectively evaluates positive sequence voltage recovery. And it also reduces negative sequence voltage. This improves the stability of the system by competency of the inverter connected to grid under the grid fault condition i.e. under voltage sag condition.

CONCLUSIONS AND FUTURE WORK

In this paper a novel voltage control scheme is proposed which is very flexible in nature so that it can adopt to various fault conditions. Also it avoids disconnection of DG under the grid fault condition. The obtained results indicates that the proposed voltage scheme is effectively compensates the voltage sag by injecting reactive power into the grid by the grid connected inverter. In case very deep voltage sag condition, the value of control parameter $k+$ has be chosen nearly equal to zero. And in case of low voltage dip condition, the balance among two extreme conditions is achieved at the time of low voltage dip condition. This proposed scheme reduces the negative sequence current and recovers positive sequence voltage.

In future for achieving protection an additional PLL scheme can be used with this proposed theory so that accurate fault should be detected [22].

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