MVT Controlled Voltage Restorer for Fault-Ride Through Capability

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***Abstract*— Voltage dips are the most harmful disturbances which affect the voltage stability of wind turbines. In voltage dip conditions, stator/rotor currents and electrical torque increase to fairly high values with failing of voltage stability. In order to provide voltage stability after the faults of voltage dips, the faults must be compensated fast and accurately. The main contribution in this study is that missing voltage technique (MVT) based controller method is tested in dynamic voltage restorer (DVR) to improve fault ride through (FRT) capability in grid connected wind systems. The proposed method controlled DVR is performed for symmetrical and asymmetrical faults in grid connected wind energy systems by using PSCAD/EMDTC power system simulator program. The case studies demonstrate the superior and effective compensation results.**

Keywords—MVT; DVR; Grid Connected Wind Systems; Voltage Dips; FRT

I. INTRODUCTION

As the ratings of wind turbines increase with the evolution of technology, power quality distortions become very important issue in the generation of electrical energy. Power quality distortions at grid voltages induce operational stability of wind energy generation systems. Among power quality distortions, voltage dips are very risky problems which distort voltage stability in grid connected wind energy systems (GCWESs). Voltage dips characterized as voltage drop from 10% to 90 % in grid voltages [1]. These faults create stator/rotor currents in unwanted high-level and failure in systems [2, 3]. Wind turbines are required to remain grid connected during voltage dips and to prevent high stator/rotor currents and failure of systems without losing the voltage stability [4-6]. This requirement is defined as fault ride through (FRT) or low –voltage ride through (LVRT) capability.

There are several protection devices to provide FRT capability in grid connected wind systems. Dynamic voltage restorer (DVR) is the most effective protection device which consists of an inverter, energy storage unit, injection transformer and output filter [7-10]. It is inserted in series in the midst of grid and turbine [11], and used to generate ac voltage by using inverter and inject controlled difference voltage via transformer during voltage dips in order to keep turbine side voltage constant in GCWESs [12, 13], as shown in Figure 1.

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In order to generate controlled voltage, voltage dips must be detected fast and correctly [14]. The speed of voltage detection in DVRs is very important issue to catch voltage dips quickly for voltage stability.

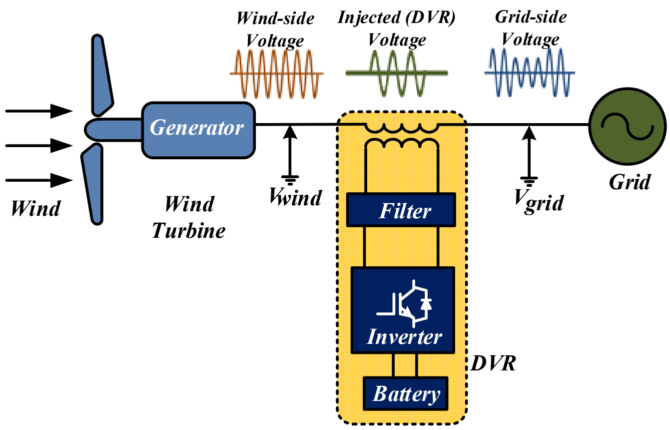


Figure 1. The location of DVR in grid connected wind energy systems

In this paper, missing voltage technique (MVT) based controller scheme is proposed in DVR system in order to generate reference signal of voltage dips for each phase. The main advantage of MVT controller is that it has very simple and effective structure. MVT controlled DVR shows superior performance for compensation of symmetrical/asymmetrical voltage dips for fault ride through (FRT) capability.

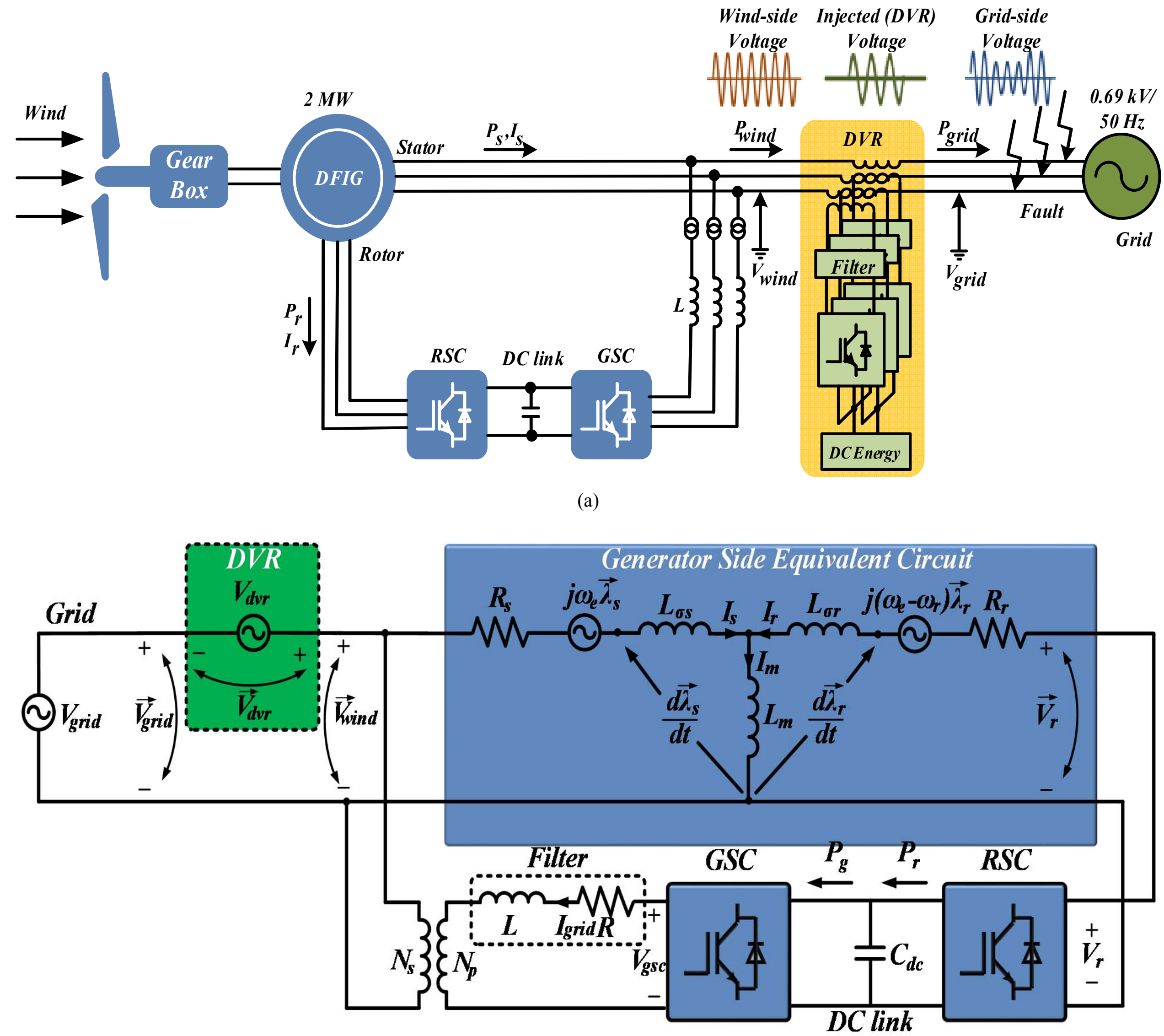
II. MVT CONTROLLED DVR

DVR based GCWES and its equivalent circuit is illustrated in Figure 2 (a) and (b). In grid connected wind systems, DVR is series tied in the interval of grid-side and wind-side [12-14]. As shown in scheme the faults of voltage dips occur at grid-side in grid connected wind energy systems. Due to faults, voltage dips occur at grid-side. In order to prevent the negative effects of voltage dips at wind-side, DVR must be provide voltage stability by injecting controlled voltage to system. As shown in the equivalent circuit, the injected DVR voltage is expressed as:

$$V_{wind}=V_{grid}+V_{dvr} \tag{1}$$

In order to compensate voltage dips and prevent the unwanted conditions due to voltage dips, grid-side voltages are firstly measured and converted to per unit (pu) values. In controller mechanism, all processes are performed in pu in order to generate voltage reference of voltage dip problems. This transformation is expressed in (2):

$$V_{grid-n,pu}=\frac{V_{grid-n}}{peak \quad value} \qquad n=a,b,c \tag{2}$$



(a)

(b)

Figure 2. DVR based grid-connected wind energy system (a) scheme and (b) the equivalent circuit

In next process, MVT is used to generate voltage difference during voltage dip. In steady-state conditions, wind-side voltage must be equal to pre-dip value of grid-side voltage during voltage dip [15]. In this way, it must be kept at reference value of grid-side value.

$$V_{wind,pu}=V_{pre-dip,pu}=(1)\times Sin(\omega t-\theta_{pre-dip}) \tag{3}$$

The grid-side voltage during voltage dip is:

$$V_{grid-dip,pu}=(Mag)\times Sin(\omega t-\theta_{dip}) \tag{4}$$

Reference voltage of voltage dip is calculated as difference between the desired instantaneous voltage ($V_{pre-dip}$) and the actual instantaneous $V_{grid-dip}$ in the course of voltage dip [16]. $V_{ref-dip}$ gives the instantaneous voltage deviation from the defined voltage signal.

$$V_{ref-dip}=V_{pre-dip}-V_{grid-dip} \tag{5}$$

$$V_{ref-dip}=(R)\times Sin(\omega t-\theta_{pre-dip}) \tag{6}$$

Where

$$R = \sqrt{1^2 + Mag^2 - 2Mag \times Cos(\theta_{dip} - \theta_{pre-dip})} \quad (7)$$

The proposed detection method, MVT, is very simple and robustness method to detect voltage dips. In addition, it can extract the voltage harmonics under distorted grid voltages due to missing voltage approach. Inverse Park Phase Locked Loop (PLL) is used to obtain phase information in MVT.

$V_{ref-dip}$ is reference signal of voltage dips which is used to generate controlled voltage via inverter. In generation of controlled voltage, $V_{ref-dip}$ is compared with carrier signals in pulse width modulation (pwm) to produce switching signals.

III. PERFORMANCE RESULTS

MVT controlled DVR is tested to provide fault-ride through capability in grid-connected wind energy system. DVR protects 0.69 kV/50 Hz wind turbine against rated up to 50% voltage dips occurred at grid-side voltages. The values of system are introduced in Table 1.

Table 1. System values

	Parameter	Value
GCWS	Voltage	690 V (line-line, rms)
	Frequency	50 Hz
	Rating	2 MW (Turbine)
	Wind speed	12 m/s
	Power Coefficient (Cp)	0.28
	Electrical power	0.6 MW
	DC-link voltage	800 V
DVR	Power Rating	300 kVA
	Inverter Type	Cascaded inverter
	Filter Inductor	0.1 mH
	Filter Capacitor	50 uF
	Energy Storage (V)	800 V
	Turn Ratio	3/1

The results of MVT controlled DVR is performed for different case studies. In order to show the strength of proposed method, the performances are carried out PSCAD/EMDTC program. In this paper, two different conditions of voltage dips are compensated to provide fault ride through capability of GCWESs. These cases are:

- 3-ϕ symmetrical voltage dips (0.5 pu for 3-phases)
- 3-ϕ symmetrical voltage dips (0.4 pu, 0.2 pu and 0.3 pu for phase a, phase b and phase c)

In first condition, 3-ϕ symmetrical voltage dips occur at grid-side voltages for 5 cycles. The magnitudes of grid-side voltages reduces from 1 pu to 0.5 pu for all phases and MVT calculates reference voltages for three phases voltage dips , as shown in Figure 3. The voltage waveforms of injected (DVR) and wind-side are presented in Figure 4. The waveforms of stator currents, rotor currents and electrical torque are illustrated in Figure 5 (a) and (b) with/without compensation respectively. It shows that DVR prevents high stator/rotor currents and electrical torque oscillations with compensation.

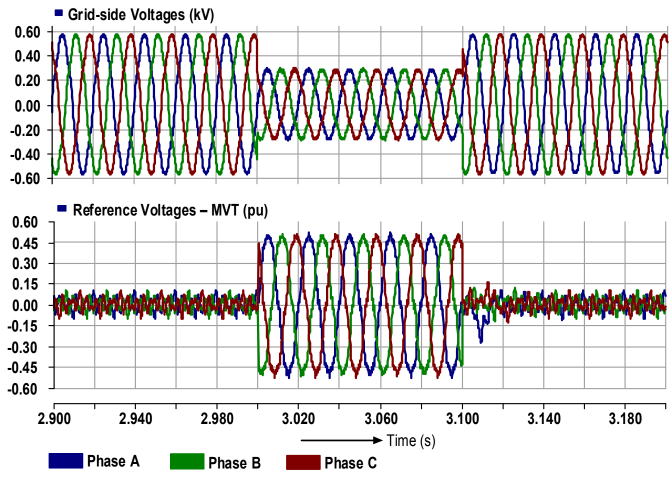


Figure 3. Grid-side voltages and reference voltages of MVT, respectively for Case I

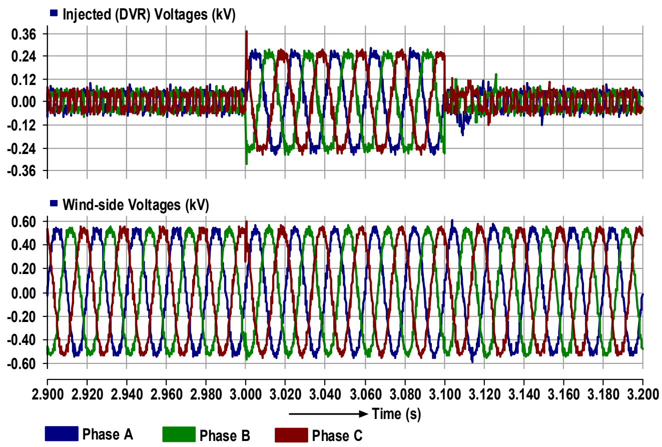


Figure 4 Injected voltages and wind-side voltages during compensation for Case I

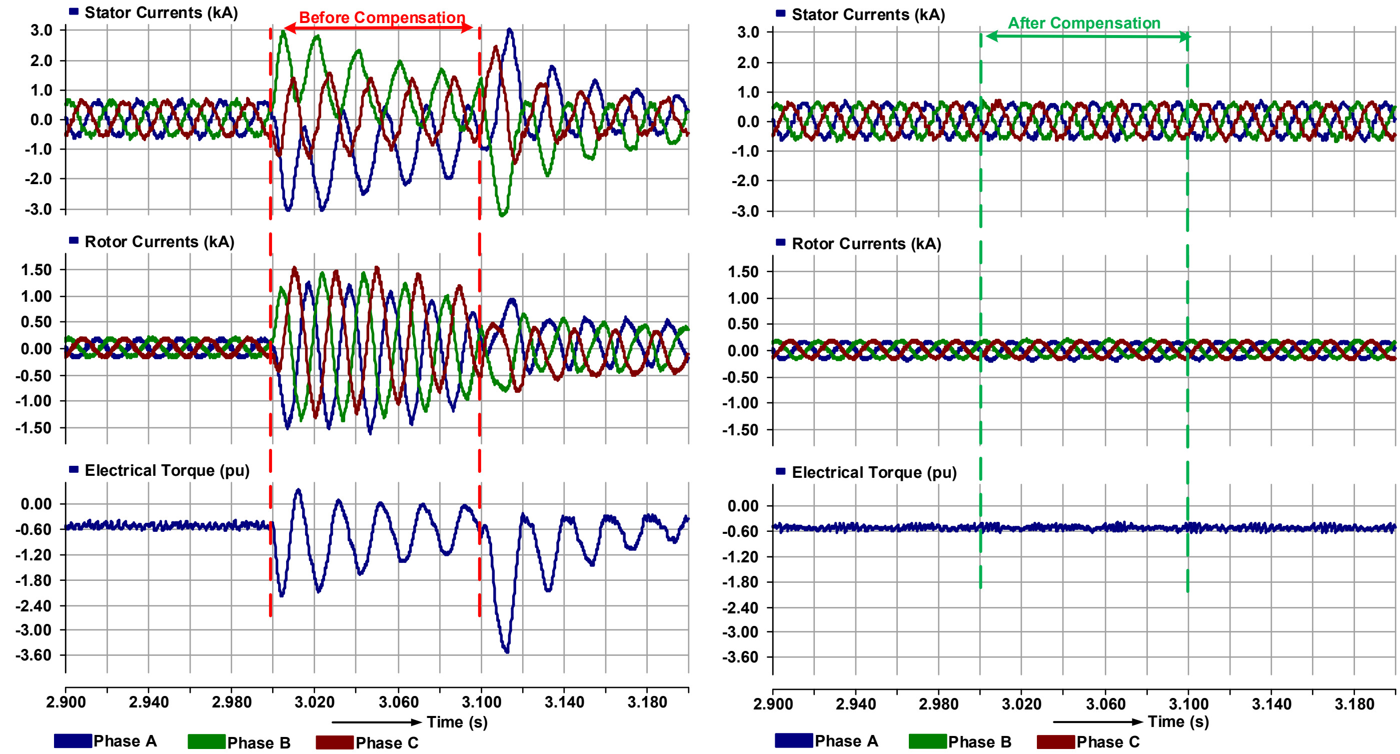


Figure 5. Stator/rotor currents and electrical torque for Case I, a) without compensation and b) with compensation

In second case of voltage dips, 3-ϕ asymmetrical voltage dips are shown for 0.1 seconds. Grid-side voltages reduce to 0.6 pu, 0.8 pu and 0.7 pu from 1 pu for phase a, phase b and phase c, respectively. The grid-side voltages and reference voltages of MVT for Case II are shown in Figure 6.

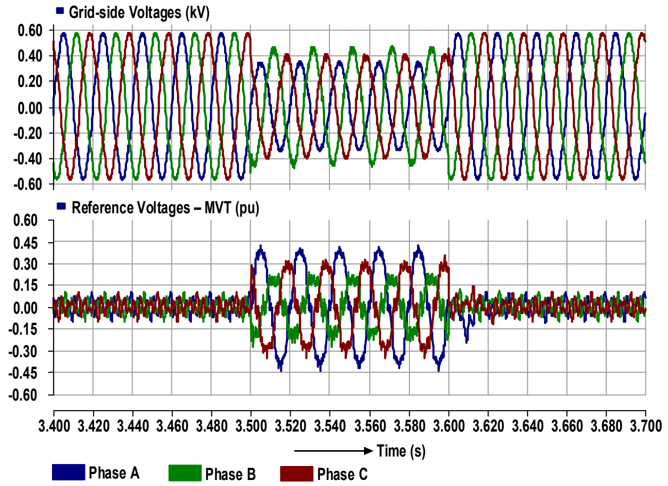


Figure 6. Grid-side voltages and reference voltages of MVT, respectively for Case II

As shown in Figure 7, DVR injects asymmetrical controlled voltages for compensation of voltage dips. Therefore, DVR achieves asymmetrical compensation and prevents high stator/rotor currents as shown in Figure 8. Figure 8 (a) and Figure 8 (b) shows the current and torque waveforms with and without compensation, respectively.

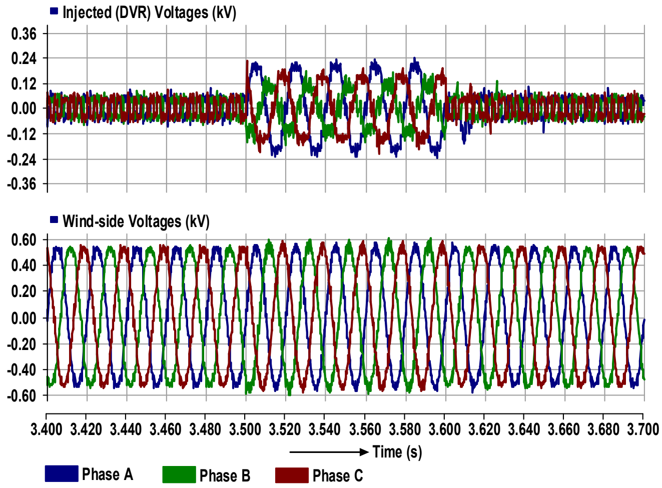


Figure 7 Injected voltages and wind-side voltages during compensation for Case II

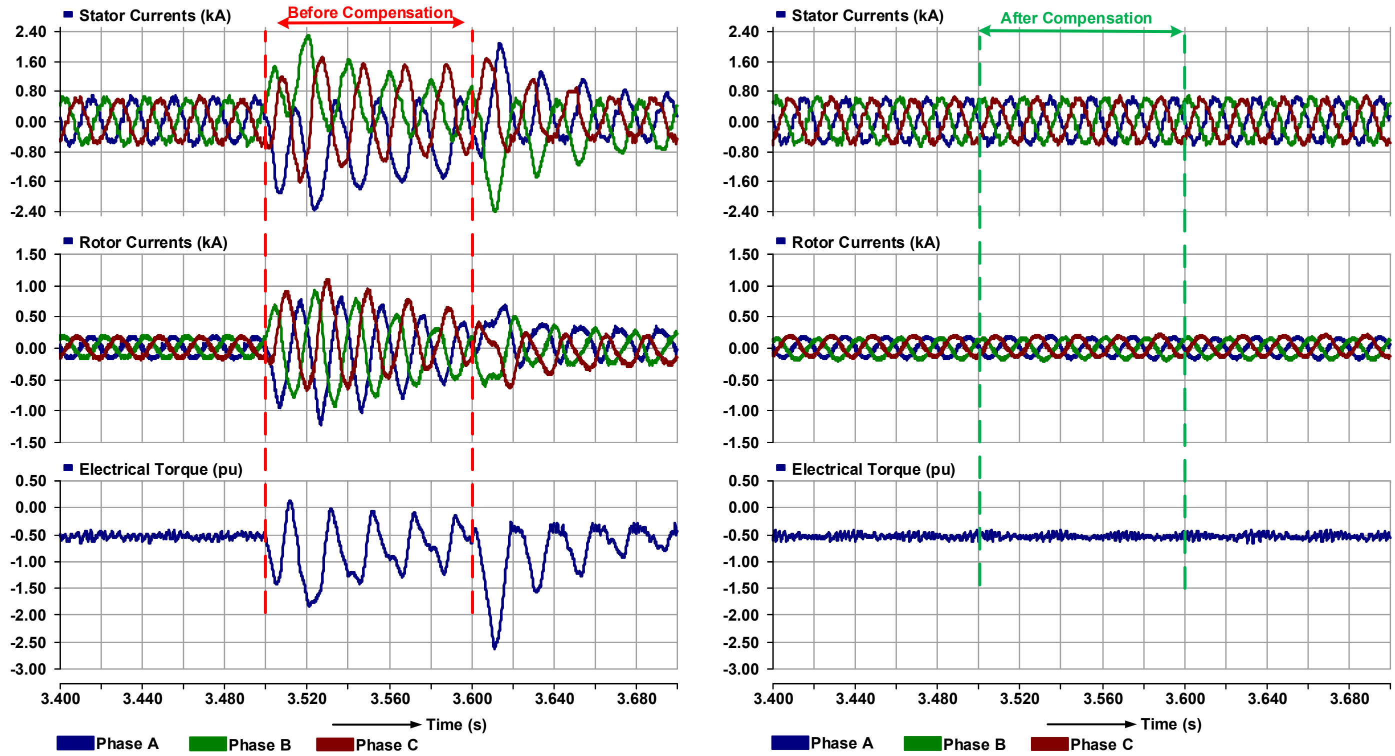


Figure 5. Stator/rotor currents and electrical torque for Case II, a) without compensation and b) with compensation

IV. CONCLUSION

In this paper, MVT controlled DVR is proposed in grid connected wind energy systems in order to keep operational stability of wind turbines during voltage dips. MVT achieves fast and accurately reference signal generation of voltage dips. İn this way, DVR can protect the wind system against voltage faults. The proposed system and controller scheme are tested to compensate voltage dips which are both symmetrical and asymmetrical. The compensation results shows very original results for fault ride through capability.

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