Improve the voltage profile of the grid-integrated induction motor with a fuzzy-based voltage source converter

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ABSTRACT

This article suggests installing a series compensator on grid-connected induction motors that allows for the ride-through of unbalanced voltage sag. Fuzzy logic controls the motor voltages in a standard three-phase voltage source inverter or voltage source inverter (VSI). An open-ended three-phase machine and the grid form a series connection for the VSI. The proposed system is well suited for uses where frequency variation is unnecessary, such as with large pumps or fans. There is no requirement for a direct current (DC) source or injection transformer when conducting an electric mutual coupling The severity of the sag in the grid voltage that will prevent EMC from shutting down is proportional to the load on the motors. An increase in the voltage of the DC link may be necessary if the voltage is not balanced. A 1.5 hp four-pole induction motor was used alongside grid voltage disturbances to test the proposed compensator's ride-through capability. Grid's current analysis demonstrates that the proposed system does not require the addition of a passive filter to achieve low levels of total harmonic distortion (THD). Additionally, the control strategy, component ratings, and analysis of the converter's output voltage operating principle and pulse width modulation technique are covered. The system's viability is shown via simulation and experimental results.

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1. INTRODUCTION

Due to their central role in most manufacturing processes, problems with machines are a common source of disruption. The induction motors are the best option for these sorts of tasks. Their effectiveness is reliant on the reliability of the input voltage [1]. Grid power quality problems can occur when machinery is supplied either directly by the utility or through adjustable speed drives (ASD) [2]. As a result, avoiding overheating and subpar performance by keeping the voltage at rated can reduce costs and negative effects on the environment. The three-phase voltage sag, or a drop in rms voltage of 0.1 to 0.9 p.u. over the course of half a cycle to 1 minute, is a common phenomenon that degrades the power quality of electrical power systems [3]. This sort of disruption typically results from a malfunction or the initial start-up of an induction motor [4]. Power electronic devices like the dynamic voltage restorer (DVR) are frequently employed for the purpose of addressing such issues. Injection transformers are used in most DVRs to transmit a voltage in a series configuration between the load and the grid [5]. Whether a digital video recorder (DVR) requires an additional power source to keep up with demand in the event of an interruption. It depends on the strategy of control and the tolerance of the operation. In this study, for induction motors, the feasibility of a series compensator with DVR function, a three-phase H-bridge topology was investigated. The equivalent circuit of the induction motor connection made using an H-bridge is a type of electrical switch that mediates the flow of electricity between the mains and the device it's powering bypassing the need for injection transformers [6]. Furthermore, the absence of passive filters is due to the inductive nature of the machine [7]. Moreover, the voltages across their DC links are stored in floating capacitors rather than being hardwired. Three-phase H-bridge converters are interesting because of their ability to control voltage, which can be used to get the machine going, improve motor efficiency, or produce reactive power.

For grid-connected induction motor applications, a three-phase equivalent circuit minimizes components as shown in Figure 1 [4]. However, it does not specify how it operates when impacted by fluctuations in grid voltage. Unbalanced three-phase voltage sag power supplies reduce induction motors' derating factor [4]. This study examines a series compensator for grid-connected induction motors that can "ride through" voltage sags. A standard three-phase voltage source inverter (VSI) links the induction motor and grid (with open-ended windings). VSI has three insulated-gate bipolar transistor (IGBT) legs and a floating capacitor.

For manufacturing equipment including compressors, centrifuges, evaporators, and agitators, the converter under investigation is an excellent choice [8]. Figure 2 [9] depicts how a three-phase H-bridge converter appears and functions. Among the uses are power factor correction, electric vehicles, improved motor performance, and series active power filters. A series compensator has also been suggested as a possible substitute for a transformer [10].

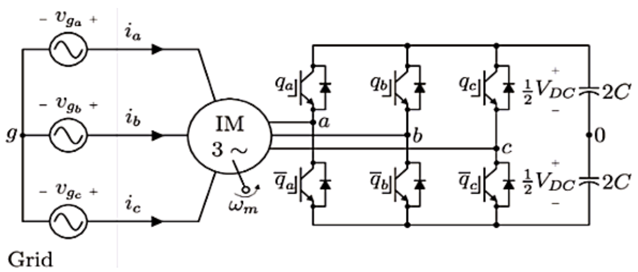


Figure 1. Equivalent circuit of induction motor [4]

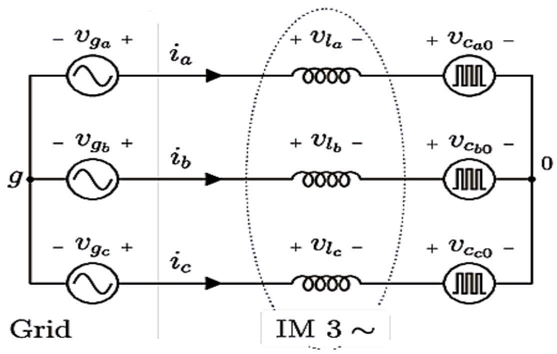


Figure 2. The equivalent circuit of the induction motor [8]

The tri-phase induction motor is protected against unbalanced power grid voltage swings by the motor equivalent circuit, which uses a simple voltage management technique derived from steady-state and dynamic system conduct [11]. The compensator only requires one direct current link and half the number of power switches required by a typical three-phase H-bridge converter. The efficacy of the system might be increased by the suggested one [1]. It is possible to synthesis only three levels of line-to-line voltage, and the VSI DC-voltage link has double the voltage of the H-bridges. Nonetheless, the THD of the grid current is well within safe bounds, and the DC voltage does not change at a rate twice that of the line frequency [12]. An uneven voltage source won't have an impact. This article elaborates on the concepts introduced in its predecessor, covering topics such as grid voltage imbalance, minimum DC-link voltage, pulse width modulation (PWM), [13] small-signal system modeling, controller parameter design, and a comparison study based on grid voltage imbalance are all topics that are talked about in this article, current total harmonic distortion (THD), component ratings, and semiconductor power losses. In this section, we discuss the operating principle, the output voltage analysis, and the control strategy. Both experimental and numerical simulation results corroborate the theory.

2. METHODOLOGIES

This is accomplished by compensating for the reference motor (v*l) and grid (vg) voltages, after which a series voltage is injected. Volts of direct current (VDC) uses active power, so energy storage is unnecessary. Energy-minimized voltage injection (EMC) is the technique used here [14]. EMC adapts the phase of the load voltage to control the current through the VSI [15]. A voltage drop analysis involves symmetrical parts. Consequently, the per-phase grid voltage phasor representation is as (1). The DC voltage level of the floating capacitor H-bridge converter has a linear relationship with the AC voltage injected by the suggested system since the PWM modulation approach utilized in this paper stays within the linear range regarding DC voltage utilization mathematical expressions are solving from equations shown in (1) and (2).

$$V_{ga}^{p.u} = \sqrt{1 - \left(V_a^{p.u} * \cos\emptyset\right)} + \left(V_a^{p.u} * \sin\emptyset\right) \tag{1}$$

Squaring on both sides

$$V_a = (V_{a+} + 1)V_g\sqrt{2}$$
$$V_a = \left(V_a^{avg} + 1\right)/m_a\sqrt{2}$$
$$V_a = \frac{\sqrt{2(V_a+V_g)}}{m_a}$$

Similarly, $V_a \cong V_{b\cong}V_c$

$$V_c = m_a \, {}^{V_{dc}}\!\big/_{2\sqrt{2}} \tag{2}$$

2.1. Analysis of voltage

There are possible to identify the cause of an unbalanced voltage drop by analyzing the disturbance's origin, the load's characteristics, and the transformer's connection to the PCC [16]. Variations in Connecting a motor to a three-phase, three-wire feeder allow for the use of both positive and negative grid voltages, which in turn allow for the use of a characteristic voltage (V) and P-N factor (F). This is due to the accuracy issues associated with measuring grid voltages [17]. Voltage imbalance is a complicated term that is used in general. The grid voltages exhibit the behavior depicted according to the phasor diagrams shown in Figures 3(a)-3(c) during unbalanced voltage sag solving (3) and (4) and (5).

$$[V_{ca} \quad V_{cb} \quad V_{cc}]T = \left[V_{gabc}\right] - [V_{Iabc}]$$
$$[\,Vgabc] \begin{bmatrix} V_{ga} \\ V_{gb} \\ V_{gc} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} V_g^+ \\ V_g^+ \\ [V_g^- \end{bmatrix} \tag{3}$$

$$[V_{Cabc}]=[V_{ca} \quad V_{cb} \quad V_{cc}]T = \left[V_{gabc}\right] - [V_{Iabc}] \tag{4}$$

$$[V_{Cabc}]=V_c^+ \, [1 \quad a \quad a^2]T + V_c^- \, [1 \quad a \quad a^2]T \tag{5}$$

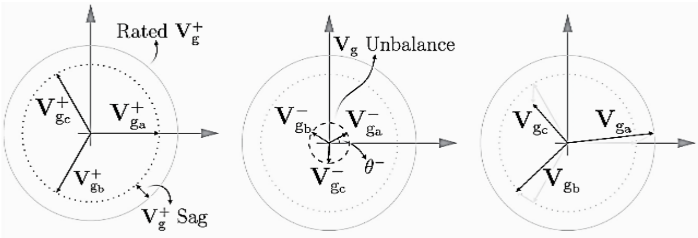
The (3) and (2) solves AC bridge for three-phase voltages with appropriate amplitude and phasing., the converter keeps the system's power balance in check while adhering to EMC's rated Vl [18]. Mean alternating current (AC) power output from [10] VSI is shown (6):

$$P_c = 3V_g^+ I\cos(\beta - \varphi_1) - 3V_1 I\cos(\varphi_1) \tag{6}$$

The (6) describes the relationship between grid voltage sag (V+g) and motor power factor, assuming rated Vl. The (4) and (5) state that Vg does not affect active power. On the other hand, as will be elaborated upon below, it affects the resulting per-phase voltages in (3) [19]. The (4) constrains Pc = 0 (EMC) for floating capacitor operation is shown in (7).

$$V_1\cos(\varphi_1) \le V_g^+$$
$$\cos(\emptyset_g) \cong 0 \; and \; \sin(\emptyset_g) \cong 1 \tag{7}$$

Figures 3(a)-3(c) [20] induce a phase shift in the voltage supplied to the motor to maintain quadrature between I and V+c (Pc = 0) [20]. During a voltage drop, the compensates for the increase in V+g and keeps Pc equal to zero. Induction motors have a poor power factor, which increases the low-voltage ride-through range. Because of this, we do not explore operations [21].



(a) (b) (c)

Figure 3. Grid voltage phasor diagram given voltage sag (a) positive V+g. (b) negative V−g. and (c) resultant Vgabc [20]

2.2. Regulations of floating capacitors

The voltage across the floating capacitor's DC connection is governed by the natural charging process when there is no voltage imbalance. equation With this method, ma is held constant, and Vc can be estimated based on the voltage of the DC link [22]. Figure 4 [23] shows the reference voltages for the converter V*cj (t) are calculated. The simplest method for generating the gating signals for the switches is a carrier-based PWM implementation. A min-max strategy may reduce voltage stress on power semiconductors and harmonic distortion with a modulation index of research [24].

Ultimately, a motor fundamental power factor angle, ϕm, can be determined since Vb is about at a 90˚ angle with respect to Vx. The battery's voltage is zero-sequence and is added in series with the reference voltages as shown in (8) & (9).

$$v_{cj}^{*}(t) = v_{gj}\,(t) - \; v_{1j}^{*}(t) \tag{8}$$

$$v_{c0j}^{*}(t) = v_{cj}\,(t) - \; v_{\mu}^{*}(t)$$
$$F_d^{\%} \; = \frac{V_g^-}{V_g^+} \times 100\% = F_d^{\%} < \theta_d \tag{9}$$

Figure 4 [23] and Figure 5 [24] in (8) and (9) equations to the phasor diagram is used to illustrate the charging and discharging operation of a floating capacitor. Compared to electrical ones, its time constant is higher, and ma might be constant.

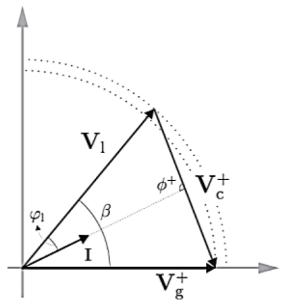


Figure 4. Discharging [23]

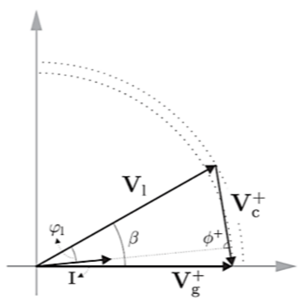


Figure 5. Charging [24]

3. FUZZY LOGIC SYSTEM

Figure 6 [25] is a common way to represent first-generation simple fuzzy logic controllers. The fuzzy input and output partitions are all known to the knowledge-based module [25]. The input variables for the fuzzy rule-base system and the output variables (control actions) for the controlled plant will be defined by a term set and their corresponding membership functions. In a fuzzy logic control system, one of the two inputs is the reference signal, which is used to determine the amount of error in the system's output [26]. The two primary inputs of a fuzzy logic controller are the magnitude of the error and the rate of change in that error [27]. This paragraph provides an in-depth explanation of the three parts that make up the fuzzy logic controller: the fuzzification stage, the inference mechanism, and the defuzzification stage. The data is subsequently sent into the fuzzy logic controller, which uses the designer-established fuzzy rules to arrive at the intended output. The output of a fuzzy logic controller is processed and then passed on to the machine or motor much like the output of any other controller [28].

Figure 7 [29] shows the proportional and integral (PI) controllers are another name for an integral controller. It combines proportional and integral control into a single mechanism. That's why we refer to it as a "PI controller." The control action of the proportional controller is combined with that of the integral controller in the proportional-integral controller [30]. VSI based on a fuzzy-PI controller for grid-integrated induction motor Figure 8 We can combine two different controllers to generate a hybrid that overcomes the shortcomings of each controller while maintaining all their advantages. In this case, the control signal is proportional to both the error signal and its integral [31]. The mathematical expression for the proportional plus integral controller is [7] as shown in (10):

$$m(t) = K_p e(t) + K_i \int e(t) \tag{10}$$

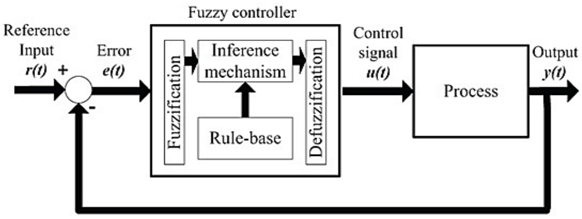


Figure 6. Simple fuzzy logic system [25]

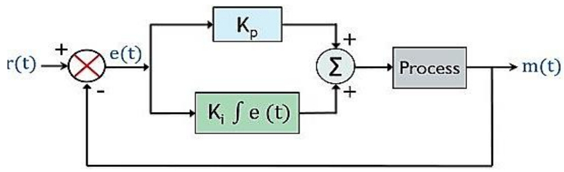


Figure 7. Control system with PI controller [29]

4. RESULTS AND DISCUSSION

Figure 8 [31] illustrates the simulation waveforms of the grid voltage, grid current and DC link voltage at balanced voltage sag at half load. Proposed Simulink for grid-integrated induction motor with a fuzzy-based controller. The grid voltage, grid current, and DC link voltage simulation waveforms with an 80% three-phase voltage sag are shown in Figure 9. The grid output voltage, current, and DC link simulation waveforms are shown in Figure 10. The grid voltage, current, and DC link voltage simulation waveforms are shown in Figure 11. A sag in imbalanced current is shown in Figure 12. The attributes of the overall induction motor torque performance as displayed in Figure 13. The attributes of the overall induction motor speed performance as displayed in Figure 14. Induction motor performance as measured by efficiency can be seen in Figure 15. It is clear from the simulated responses that the voltage sag: DC link capacitor regulated the voltage and made IM torque and speed constant. Employing the proposed control approach based on a half-bridge converter, acceptable steady state and transient responses of the IM are achieved despite grid disturbances. the output Vs duty cycle performance characteristics of total performance of load, speed, torque, current, output voltage overall efficiency. The simulation waveforms of the 360-degree performance of induction motor.

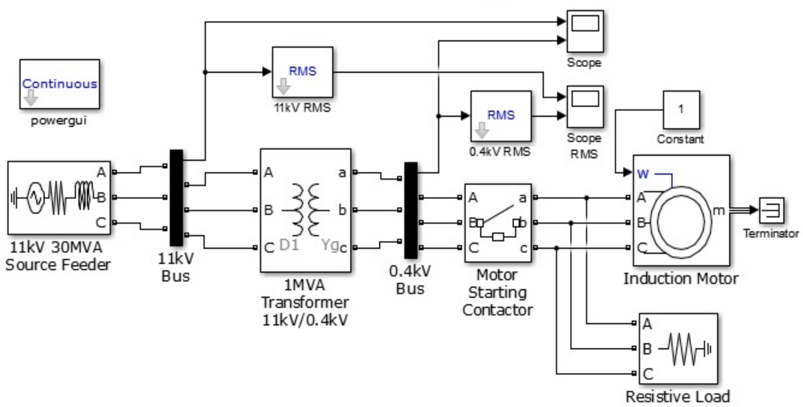


Figure 8. Fuzzy-PI-controller-based VSI for grid-integrated induction motor [30]

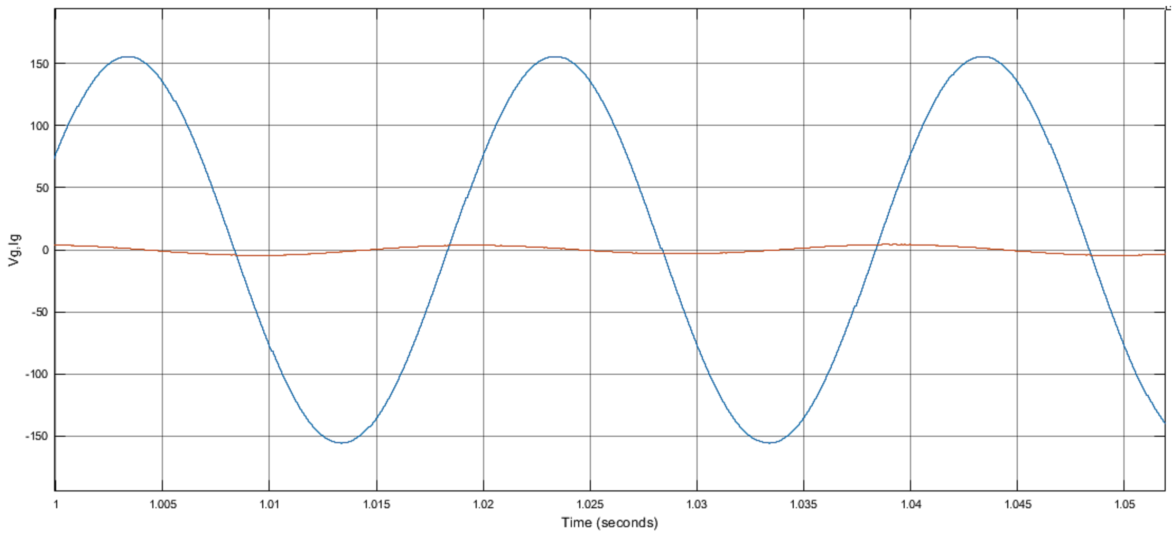


Figure 9. Input grid voltage (Vg), grid current (Ig)

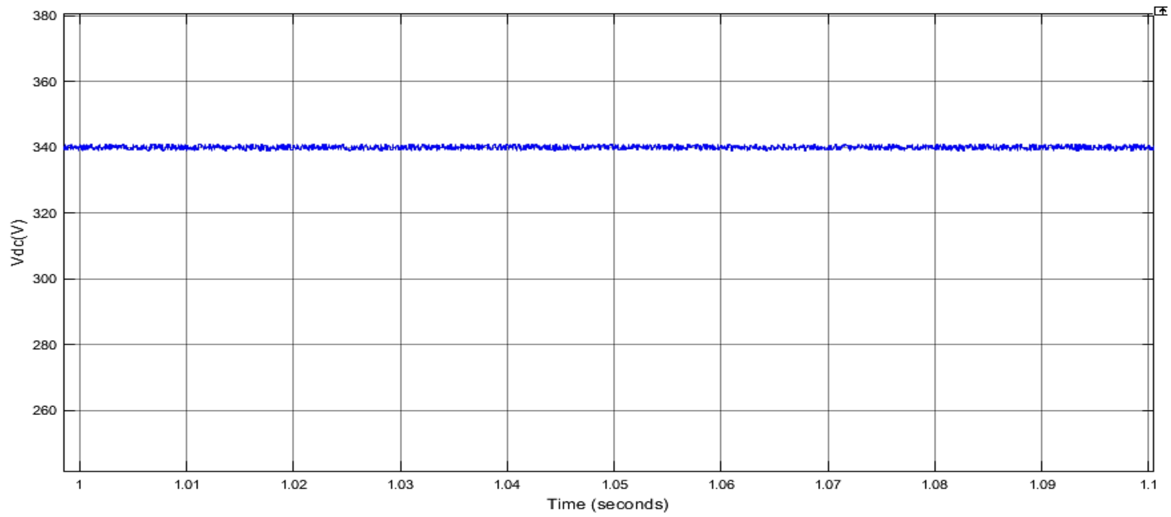


Figure 10. Output DC link voltage (Vdc)

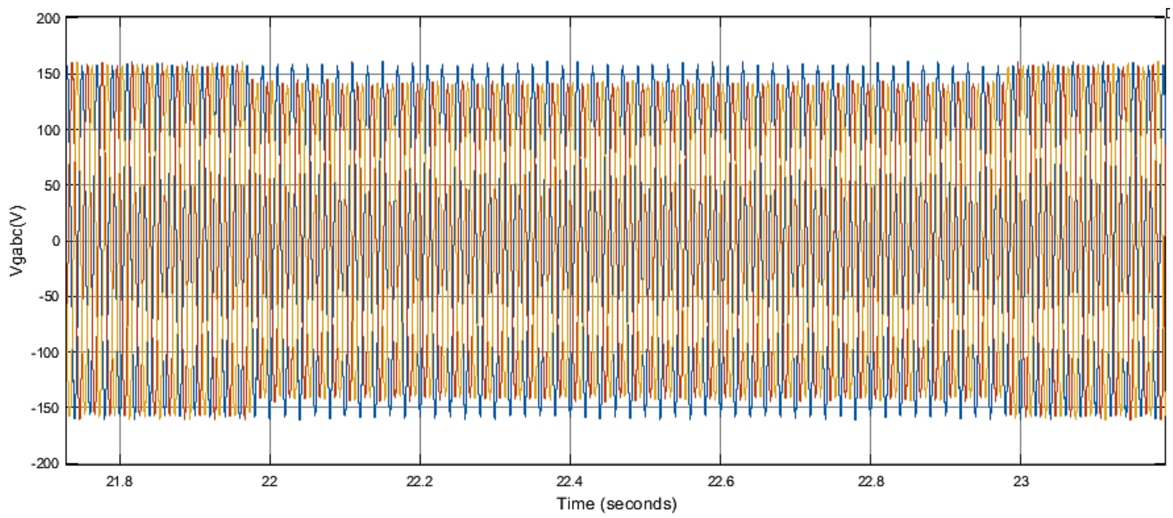


Figure 11. Three-phase grid voltage (Vgabc)

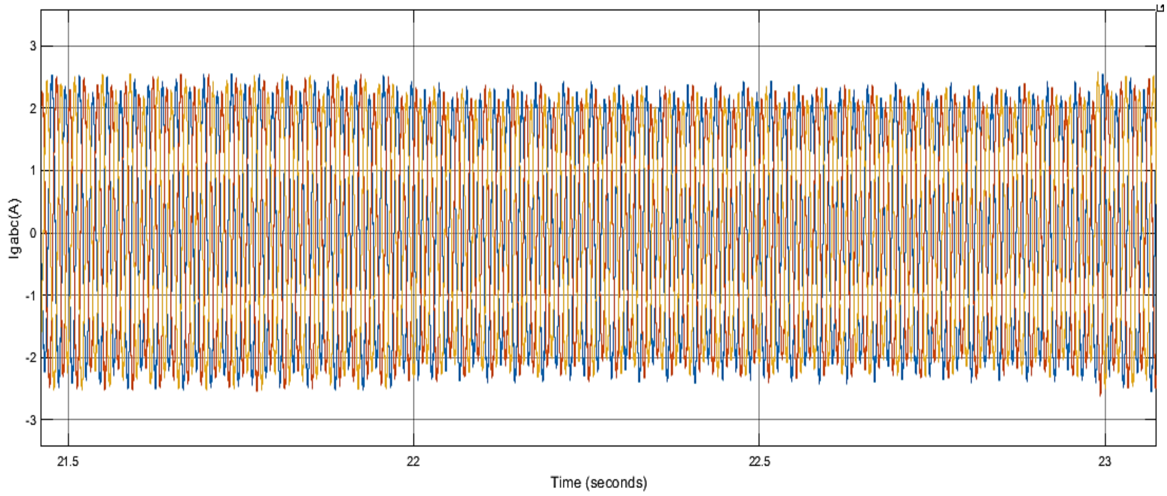


Figure 12. Grid current (Igabc)

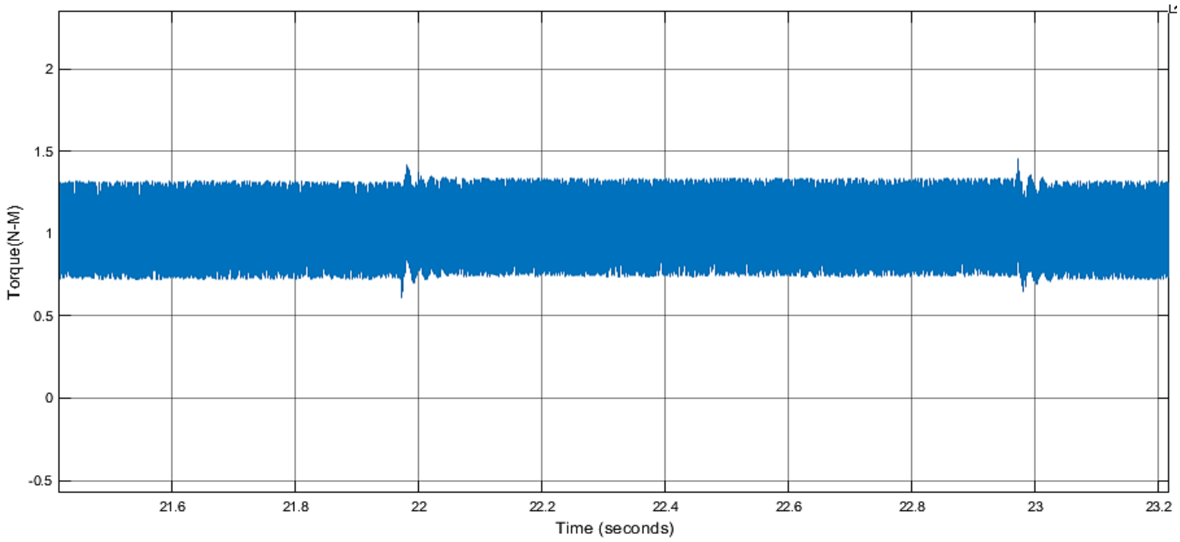


Figure 13. Torque (Nm)

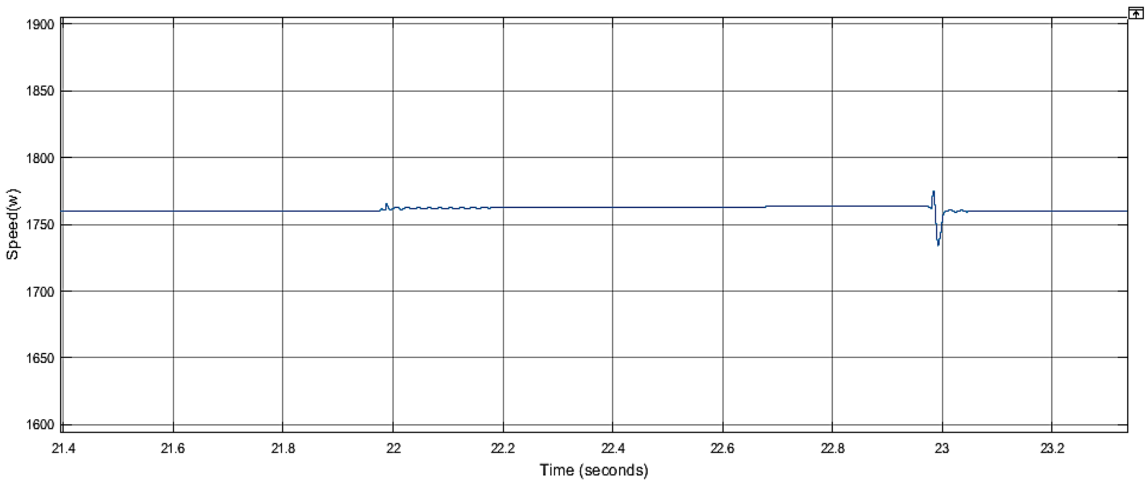


Figure 14. Speed (rpm)

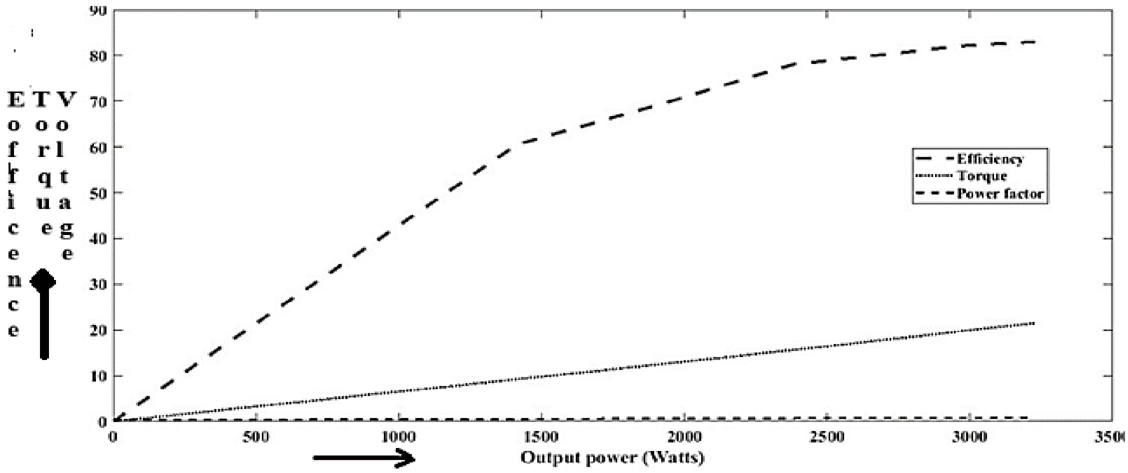


Figure 15. Output performance of efficiency of induction motor

5. CONCLUSION

The proposed system can "ride through" unbalanced voltage sags for grid-connected induction motors. Both theory and practice supported its conclusions. VSI is used in series three-step equalizers with a floating DC-link capacitor. No energy supply, injection transformer, or passive filter are required for the suggested setup. Typical phrase: three-phase, conventional H-bridge converter for regulated grid voltage disturbances. This solution uses fewer parts, only one DC connection, and can handle imbalanced voltages without sophisticated mechanisms for regulation. The series compensator was proposed as a solution to the primary problem, which was an increase in the voltage of the DC link. THD of grid currents was high despite the proposed remedy. When there is no frequency change, squirrel-cage induction motors are used. The fuzzy-based controller is required to improve the grid-integrated induction motor voltage profile

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