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Analysis of Sudden Short Circuit Faults in 5KVA Single Phase Synchronous Generator

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Abstract- This paper presents a comprehensive review of faults in electrical machines as well as single-phase synchronous generators. The work was divided into five parts. The first pat is introduction which gives a vivid explanation of synchronous generator and what single phase generators are used in enhancing power supply as a standalone power source. Part two centered on the literature review and an overview of the faults in single phase synchronous generator. Faults in stator and Rotor windings were elaborately discussed. Modelling of single phase synchronous generator using mathematical models was what is contained in part three. Here, all the equations of the machines parameters were defined. Short circuit faults was discussed in part four which contained the effects of sudden short circuit faults. Sub – transient, transient and steady state conditions of a single phase generator under sudden short circuit fault. The last part is conclusion which is contained the summary of the work.

Keywords: Short Circuit, Faults, Stator Winding, Rotor Winding, Voltage And Current

I. INTRODUCTION

Renewable energy is gaining tremendous attention in recent years, therefore study into the use of renewable energy sources like hydro power, wind and photovoltaic plants for electricity generation has been the concept of increased attention (Rahim et al 2003 and Ahmed et al, 2007). Additionally, small units that supply electricity in isolated or distant locations that are either outside the reach of an electric power grid or cannot be profitably connected to it are of interest.

(S.S Apeshi et al, 2019). Most conventional generators like three phase alternators are used in the generation of electricity and supply at the moment and each of them have different advantages and disadvantages.

Epileptic nature of power supply in Nigeria has made stand-alone single-phase generators helps residentially homes, medium and small companies, hospitals, schools etc in powering their premises. Single phase synchronous generators are alternatively used for electricity generation in autonomous cases because of their advantages over others like three phase. Single phase generators are also handy to travel with considering that many families travel during festive times like Christmas, Easter etc which easily provide source of power to the family instead of installing renewable energy for stay that will be very short. Also, small capacity (0.5 – 3KVA) single – phase synchronous generators are utilized in locations where the grid is either inaccessible or where power supply is unreliable. Such generators are driven by small petrol engines and have been in existence for over seven decades (S.S.Apeshi et al 2019). Below are pictures of single - phase synchronous generator.

Furthermore, following population growth in some developing countries (ie Nigeria) which are not correspondingly matched by growth in electrical energy supply, grid system supply inefficiencies interested and therefore these generators are rapidly becoming a greater part of electricity supply in both rural and urban homes and small commercial outfits (S.S.Apeshi et al 2019) and (Terry and Robertson, 1948).When a synchronous machine is in the steady state, its speed remains constant. In a synchronous machine, the rotor and the spinning air gap field revolve at the same speed under steady state conditions. This speed is known as the synchronous speed and is determined by the number of field poles and the frequency of the armature current. The main function of synchronous machines is to generate electricity and are known as alternators in this context. Synchronous generators are the major machines for energy conversion that converts mechanical energy to electrical energy globaly for electric power systems.It is referred to as a synchronous generator because the rotor's rotational speed is equal to the stator's magnetic field rotational speed. The synchronous speed is the consequence of the rotor's rotational speed when the magnetic poles rotate at the same rate as the stator's rotating field. (Apkeshi et al 2019 and Hubert, 1991).

Two major components of ynchronous generator are (a) rotor windings or field windings which is also classified into salient pole and Non salient pole (cylindrical rotor) (b) stator windings or armature windings. As long as the armature rotates and a magnetic field is present, a single-phase synchronous generator generates voltage in a single wave that alternates. The voltage produced by this kind of generator varies with the wave cycle.

In a single – phase synchronous generator, the rotor resemble that of a three phase generator, stator is wound single – phase with full-pitched coils. However, one third of stator slots are left unwound and winding is a single layer winding (there is no compulsion of 1/3 to be left open). The key requirement is that the windings should be as sinusoidal as possible. The rotor is made of salient poles and produces a field distributed sinusoidally in space because of the shaping of the pole faces as well as oscillating field along a fixed axis is produced by the stator which is the single phase. Additionally, this generator is among the most crucial pieces of equipment in the power system that provides consumers with electrical energy. Although synchronous generators are incredibly dependable devices, they are prone to inevitable malfunctions that could disrupt the electrical power supply.Numerous protection strategies have been put out thus far to improve power system reliability since synchronous generator dependability is a crucial problem in power systems; nevertheless, these strategies will raise the cost, volume, and weight of the power production system,(Mohesen and Jawad, 2021),

Synchronous machines are useful electromechanical energy-conversion devices, which are used in the generation of electricity and in industries for certain special drive applications. Synchronous generators convert mechanical energy from the hydro, steam turbines and diesel or fuel engines into electric energy. There have been a lot of work on the fault detection and analysis of induction machines, but little works have been done on synchronous generator faults detections as well as analysis. The reasons include complicated structure and difficult starting process of the generator.

II. LITERATURE REVIEW

Research work on single-phase synchronous generator is not common because the machine is basically being used in third world countries especially Africa. Analysis of faults in synchronous generator can be done using model based (using physics based mathematical models), data driven or hybrid approaches (Narasimhan et al, 2010). A model-based approach is advised for well-known and basic systems. To study the machine's components, a mathematical model of the system should be accessible,(Gopinath et al, 2021).. This is the need for the modelling of the generator using the exact capacity of the generator under study. According to, Nanidi, Toliyat & Li, 2005; Siddique, Yadava, & Singh , 2005, indicates that fault modeling can be done using exactly similar machine/machines for which diagnosis is to be performed. Given the significance of the generator, it is clear that accurate generator modeling is essential for all power system engineering research, (Adkins and Herley, 1975). Nonetheless, numerous synchronous machine models were created which are in literature, and each one has a specific set of machine parameters. Many academics have looked into the characterization and precise determination of the synchronous machine parameters. It must be mentioned that a sizable portion of the test methods used to determine the synchronous machine parameters are put together in IEEE standards, (IEEE guide, IEEE standard, 115 – 1995, 1995) and IEC standards (IEC 34-4 1985, 1985).Many works or articles give various machine test procedures for the estimation of the synchronous machine parameters in addition to established processes. The method of Load rejection as shown in (Zaker et al ,2018)and (Gutierrez et al, 2017) is commonly used test for evaluation of the parameters. However, in this work, the parameters were obtained from direct measurement of the dimensions of the generator.

a. FAULTS IN SINGLE PHASE SYNCHRONOUS GENERATOR

An electrical machine fault results from aging, manufacture mistakes, and improper operation, which limits the equipment's performance to a minimum of its specified capabilities. A combination of these and numerous other factors could possibly be the cause. If a defect is not identified and fixed, it will typically worsen over time and cause the system to completely fail.

(Yaw, 2013 and Thorsen and Dalva, 1999). The synchronous generators are robust machines and

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faults which are certain to occur do interrupt the electrical power supply from such machines. The various faults which can occur in generators can be classified as; (i) Stator faults (ii) Rotor faults and (iii) Abnormal faults. In large synchronous generators, the most common fault is the stator – winding fault, followed by the the rotor-winding faults. In addition to harming the machine, an internal issue in the SG could result in failure and lost of income. Therefore, in order to increase the power generators' availability and dependability, it is critical to identify any synchronous generator faults as soon as it is feasible. (Panmanabhan et al 2016 and Sivakumar et al 2013).

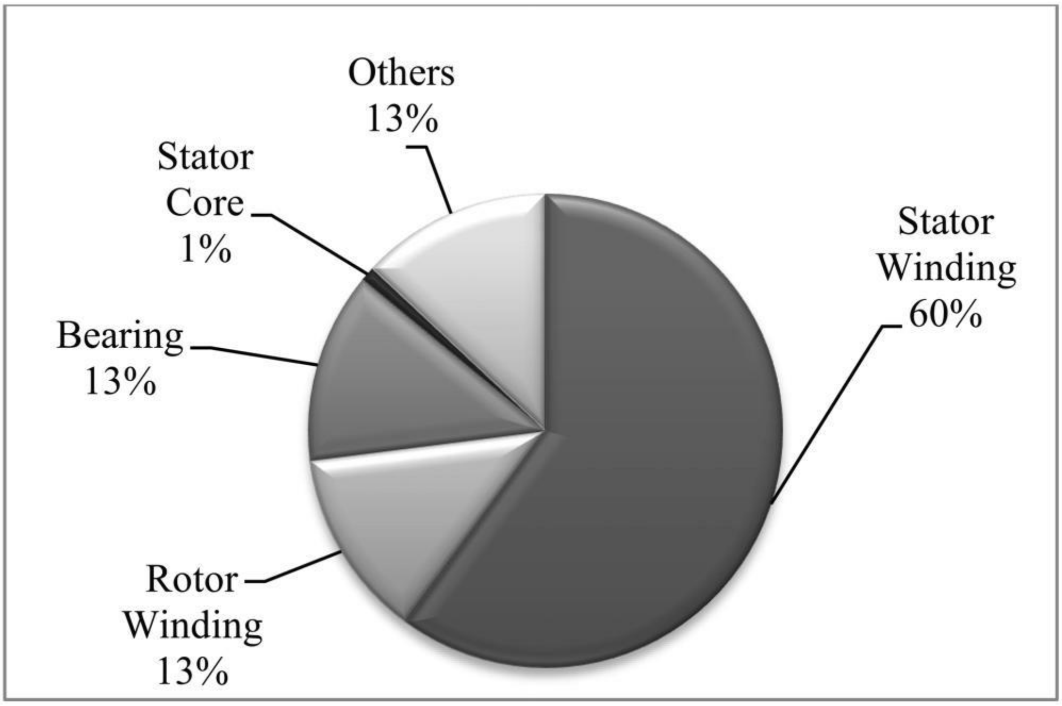

Fig. 1 Faults percentages in Electrical machines.

Faults in electrical machines can be categorized into two groups: electrical and mechanical faults. According to (Tayner, 2008), mechanical faults include broken damper bars, bearing failure, rotor mechanical integrity failure, and stator mechanical integrity failure while electrical faults include core insulation failure, stator windings or their insulation failure, and rotor winding or its insulation failure.

According to (Yaw, 2013 and Nandi and Toliyat, 1998), faults that are suffered by electrical machines are the followings; demagnetization faults, gearbox and bearing faults, rotor field winding short circuits, stator field winding short circuits, broken rotor bars, wrong stator and rotor winding connections, static and dynamic eccentricity, turn to ground faults as well as shearing between stator and rotor bars,

i. Faults in Stator Windings.

Faults in the stator are primarily caused by the insulation failure in the stator windings and they are classified as (i) Phase- phase faults (ii) Phase – earth faults (iii) Inter – turn faults. Figure (1) shows that 60% of fault that occur in electrical machine including synchronous generator is at the stator windings. The major causes of faults in stator windings are electrical discharge, insulation degradation, mechanical stress, magnetic force, high temperature, and short circuit, (Nandi, 2004). The phase - phase and phase – ground faults are more harmful to the electrical machine than inter – turn winding faults but inter – turn can easily be detected. Stator winding faults is one of the most common faults in electrical generators (IEEE, pg-689; 2007 and Padmanabhan et al 2016).

The following have been shown to be the most frequent causes of stator-related faults: partial leaks in the insulation of the windings, high temperature of the stator core, De-lamination of joints, slot wedges, and stator cores the windings short circuiting, Defective cooling systems, chemical contamination, supply voltage strains, and disconnected end winding bracing.

ii.Faults in Rotor Windings.

Electrical and mechanical faults can occur in the rotors due to the rotating nature of rotor faults that occur in rotor are very frequent depending on the type of machines and type of applications the machines as engaged. They are also very complex and diagnosing faults is also hard.. According (Yaw, 2013), broken rotor bars and end rings, rotor winding short circuits, demagnetization, eccentricity of the rotor bars, and displacement of magnetic poles are among the rotor winding problems that have been identified in the literature and industry. However, rotor windings also experience short circuit faults. The rotor winding in a synchronous generator is responsible for producing the magnetic field. Any fault in these windings compromise the magnetic field, which directly affects the generator's ability to produce consistent and stable voltage. The most common rotor faults found in the literature and industry according to Yaw (2013) are listed as follows; broken rotor bars and end-rings, rotor winding short-circuits, demagnetization, eccentricity of the rotor bars and magnetic pole displacements.

III. MODELLING OF 5KVA SINGLE – PHASE SYNCHRONOUS GENERATOR

Figure 2 shows the schematic diagram of a Single phase synchronous generator.

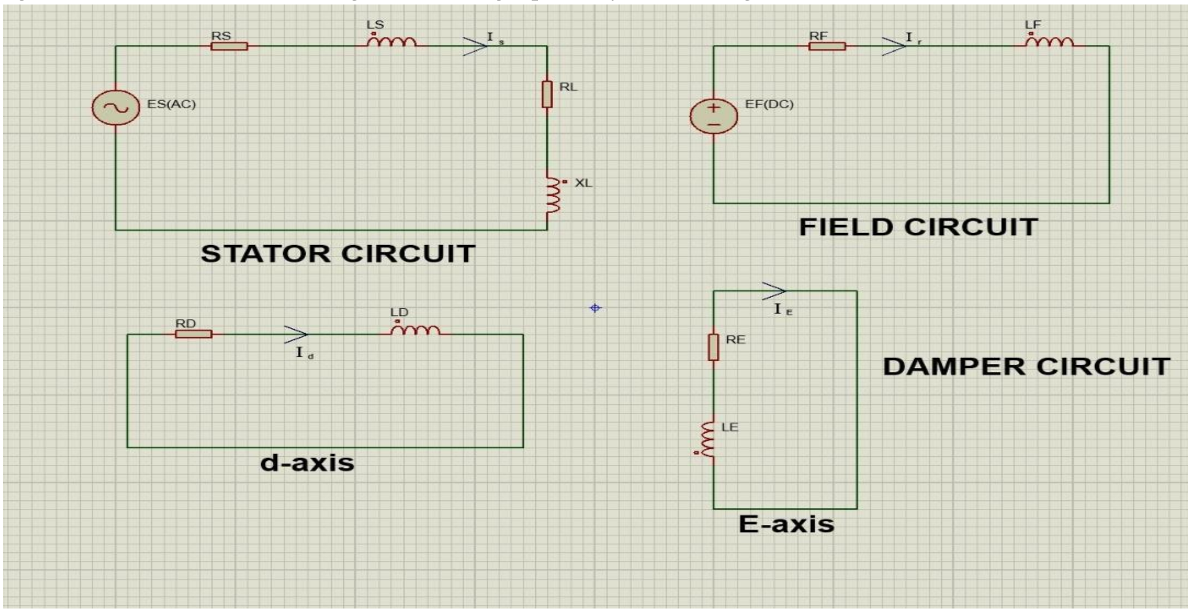

Figure 2. This is a two-pole salient pole single phase synchronous generator.

It is crucial to use a mathematical model that accurately depicts the synchronous generator in order to produce state estimate equations for a single-phase synchronous generator and the conditions being studied.

This model consists of one stator windings, one field winding and two damper windings for q-axis and d-axis respectively as indicated in Figure 2 Since the rotor position affects the magnetic coupling, the flux connecting each winding likewise depends on the rotor position (Tavner.P and Penman.J, 1987) The machine's stator windings are identical and dispersed sinusoidally.

The windings comprises of starting coils and running coils which can also be seen as the phase winding (s) and field winding (f). Short circuited dampers or amortisseur windings (kd and kq windings) can be used to simulate the electrical properties of this synchronous machine (generator).

These damper coils (windings) are short – circuited that shows the paths for currents induced in the rotor. The rotor is a laminated salient – pole rotor core. According to (Krause P.C in chapter 6 page 219) windings are approximated by two sinusoidally distributed windings which are separated by electrical degree (90^0). The d-axis damper winging k_d has the similar magnetic axis as the field winding f_d which has equivalent turns of N_{kd} with resistance of r_{kd} .The magnetic axis of k_q winding is

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leading the magnetic axis of f_d and k_d windings by 90º with equivalent turns of N_{kq} and resistance r_{kq} .The q-axis is the magnetic axis of the k_q winding whereas the d-axis is the magnetic axis for the f_d and k_d windings. (Krause P.C in chapter 6 page 220) of Electromechanical motion devices that the q and d are introverted to symbolize the synchronous machine's rotor magnetic axes of a synchronous machine, Regardless of any transformation, they have been linked to the rotor's physical structure.

According to figure 2, the rotor electrical angular velocity is the angular displacement about the rotor, which is related to the q-axis and ω_r is the rotor electrical angular velocity. Also the electrical angular displacement of the rotor measured from the as axis to the q-axis is θ_r . Due to the non-uniform air gap the salient pole synchronous machine (generator), the magnetic characteristics of the q and d axes are not the same. From the literature point of view, fault modeling has to be done using exactly similar machine/machines as that which analysis has be performed (Nanidi, Toliyat & Li, 2005; Siddique, Yadava & Singh, 2005) and in this research a single phase 3kVA was used as a model to analyze the short circuit behavior of a 5KVA single phase synchronous generator.

Voltage equation of Single phase Synchronous Generator.

The equivalent circuit of the single phase synchronous generator is shown below figure. 3 where (a) is the stator equivalent circuit and (b) represents the rotor equivalent circuits.

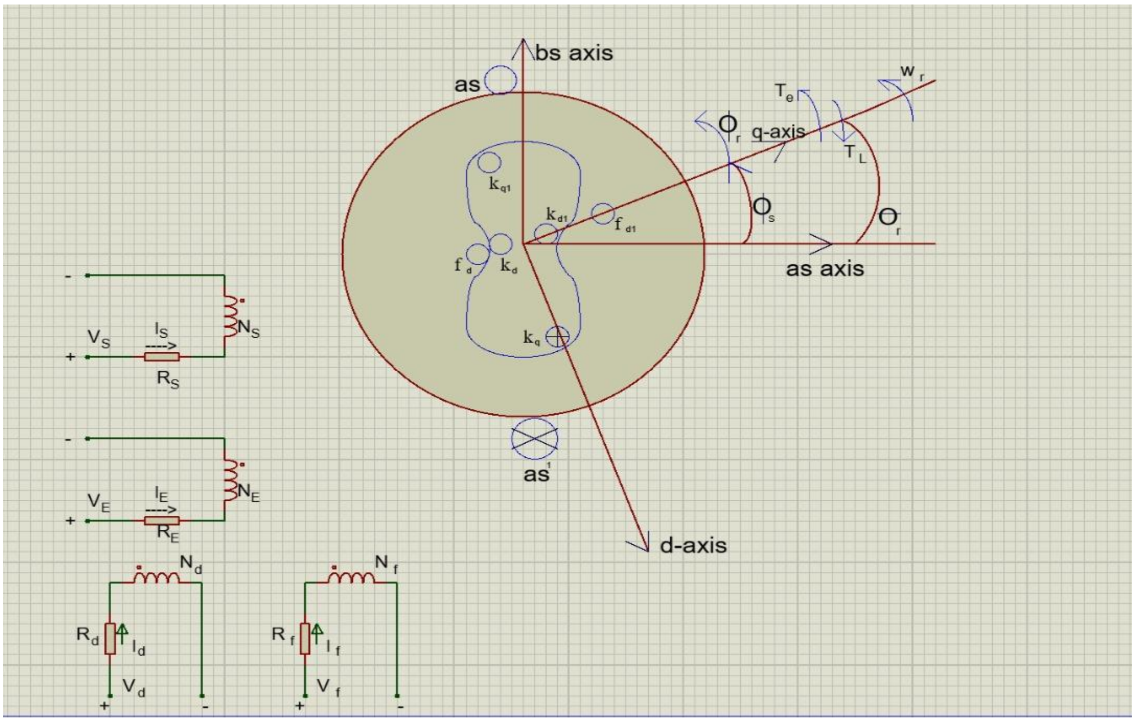

Fig 3 A single-phase synchronous generator's equivalent circuit.

A voltage (emf) Es is induced in the stator, which produces an alternating current through the running coils in the stator while the field winding is for the starting of the generator using voltage, emf by direct current application to the field winding.

From figure 3, the winding circuits in the rotor are short circuited and makes voltage induced to be zero in both q and d axes windings. The voltage equations are expressed using equation 3.1 for each circuit.

$$V = IR + \frac{d}{dt}(LI) \quad 3.1$$

The voltage equation for both the stator and rotor circuits are given as:

$$V_s = E_s = I_s R_s + \rho\lambda_s \quad 3.2$$

$$V_f = E_f = I_f R_f + \rho\lambda_f \quad 3.3$$

$$V_d = I_d R_d + \rho\lambda_d \quad 3.4$$

$$V_q = I_q R_q + \rho \lambda_q \qquad 3.5$$

Expressing equations 3.2 – 3.5 in matrix format will give us:

$$\begin{bmatrix} V_s \\ V_f \\ V_d \\ V_q \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 & 0 \\ 0 & R_f & 0 & 0 \\ 0 & 0 & R_d & 0 \\ 0 & 0 & 0 & R_q \end{bmatrix} \begin{bmatrix} I_s \\ I_f \\ I_d \\ I_q \end{bmatrix} + \rho \begin{bmatrix} \lambda_s \\ \lambda_f \\ \lambda_d \\ \lambda_q \end{bmatrix} \qquad 3.6$$

The flux linkages for the windings are; λ_s is stator winding flux linkage while λ_f is the field winding flux linkage. λ_d and λ_q are the q-axis and d-axis of the rotor winding flux linkages respectively. The differential operator $\frac{d}{dt}$ is expressed as ρ.The stator winding current is I_s while the current of the field winding is I_f. Further, the rotor windings currents for d-axis and q-axis windings are I_d and I_q respectively. Currents, self and mutual inductances of the machine are the electrical functions used to articulate stator and rotor flux linkages,

The flux linkages are:

$$\lambda_s = (L_{aa} + L_{af} + L_{ad} + L_{aq}) I_S \qquad 3.7$$

$$\lambda_f = (L_{fa} + L_{ff} + L_{fd} + L_{fq}) I_f \qquad 3.8$$

$$\lambda_d = (L_{da} + L_{df} + L_{dd} + L_{dq}) I_d \qquad 3.9$$

$$\lambda_q = (L_{qa} + L_{qf} + L_{qd} + L_{qq}) I_q \qquad 3.10$$

However, expressing equation 3.6 – 3.9 in matrix form produces thus:

$$\begin{bmatrix} \lambda_s \\ \lambda_f \\ \lambda_d \\ \lambda_q \end{bmatrix} = \begin{bmatrix} L_{aa} & L_{af} & L_{ad} & L_{aq} \\ L_{fa} & L_{ff} & L_{fd} & L_{fq} \\ L_{da} & L_{df} & L_{dd} & L_{dq} \\ L_{qa} & L_{qf} & L_{qd} & L_{qq} \end{bmatrix} \begin{bmatrix} I_s \\ I_f \\ I_d \\ I_q \end{bmatrix} \qquad 3.11$$

The inductances comprises of

(i) Stator winding – field winding inductances (L_{sf})
(ii) Stator winding , field winding and rotor winding inductances (L_{sfr})
(iii) Rotor winding , stator winding and field winding inductances (L_{rsf})
(iv) Rotor d-axis and q-axis inductances (L_{rr})

These inductances are represented in matrix form as follows.

$$L_{sf} = \begin{bmatrix} L_{aa} & L_{af} \\ L_{fa} & L_{ff} \end{bmatrix} \qquad 3.12$$

$$L_{sfr} = \begin{bmatrix} L_{ad} & L_{aq} \\ L_{fd} & L_{fq} \end{bmatrix} \qquad 3.13$$

$$L_{rsf} = \begin{bmatrix} L_{da} & L_{df} \\ L_{qa} & L_{qf} \end{bmatrix} \qquad 3.14$$

$$L_{rr} = \begin{bmatrix} L_{dd} & L_{dq} \\ L_{qd} & L_{qq} \end{bmatrix} \qquad 3.15$$

Substituting equation 3.11 into equation 3.6 will produce;

$$\begin{bmatrix} E_s \\ E_f \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 & 0 \\ 0 & R_f & 0 & 0 \\ 0 & 0 & R_d & 0 \\ 0 & 0 & 0 & R_q \end{bmatrix} \begin{bmatrix} I_s \\ I_f \\ I_d \\ I_q \end{bmatrix} + \rho \begin{bmatrix} L_{aa} & L_{af} & L_{ad} & L_{aq} \\ L_{fa} & L_{ff} & L_{fd} & L_{fq} \\ L_{da} & L_{df} & L_{dd} & L_{dq} \\ L_{qa} & L_{qf} & L_{qd} & L_{qq} \end{bmatrix} \begin{bmatrix} I_s \\ I_f \\ I_d \\ I_q \end{bmatrix}$$
3.16

IV.SHORT CIRCUIT FAULTS

A short circuit fault is electrical fault that occurs when two points in an electric circuit that are not meant to come together do so thereby allowing current to take an unintended, low – resistance path. This lead to large increase in current which can cause overheating, machine damage, tripping of protective devices and fires.

However, when there is a sudden short circuit fault in single phase synchronous generators, the followings are observed;

a). High fault Current (Surge Current).
Short circuit causes generator terminals to experience very low impedance which allow large volume of current to flow. This also cause transient fault current which can rise from 5 to 10 times the rated current depending on the rating of the generator.

b). Rotor experiences Mechanical stress.
This sudden change in the system especially the armature can generate non – uniform magnetic forces on the rotor. These forces will lead to vibration, shaft

stress and Possible mechanical damage to the rotor and bearing.

c). Electromagnetic Torque Oscillations.
There is also a sudden change in the interaction between magnetic fields of both stator and rotor windings which result in pulsation or oscillating torques. These torque oscillations can destabilize operation of the generator mainly during transient recovery.

d). Terminal voltage Collapse.
At the sudden short circuit fault in a single phase generator, terminal voltage reduces nearly to zero instantly. This situation can destroy connected equipment or affect voltage stability of the total power system.

e). Severe thermal stress.
The high current due to sudden short circuit fault causes rapid heating in the stator windings and in the rotor through induced currents. However, delay in clearing the fault can destroy insulation, burn windings or lead to permanent failure.

Graphs of Currents during short circuit faults are shown in figures 5 and 6.

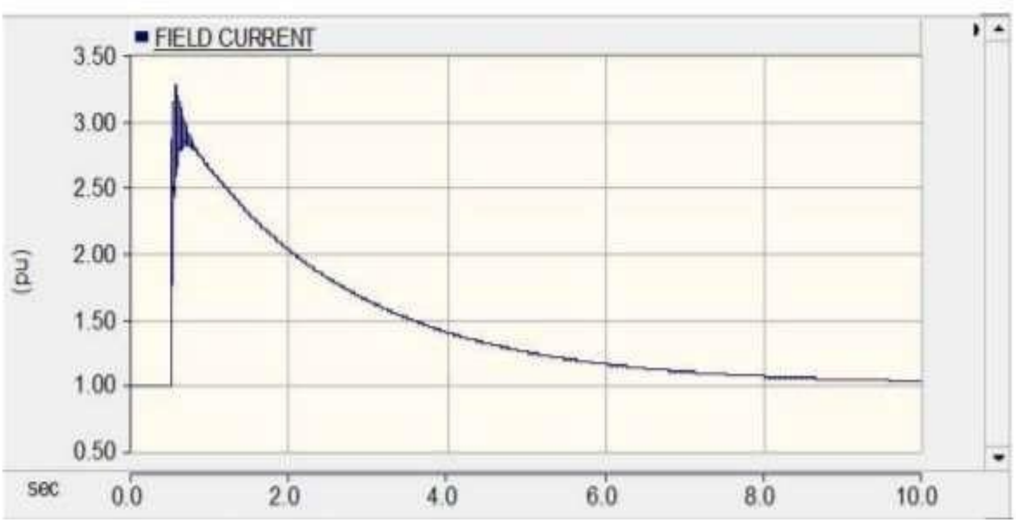

Fig. 5 Field current of Salient Pole Generator with Dampers of 5KVA single phase synchronous generator (Deepthi et al, 2020).

When the generator is under sudden circuit fault, the currents are affected. The field current on the damper winding is shown in figure 5. There is sudden rise in current between 1 – 10seconds depending on the size and rating of the generator.

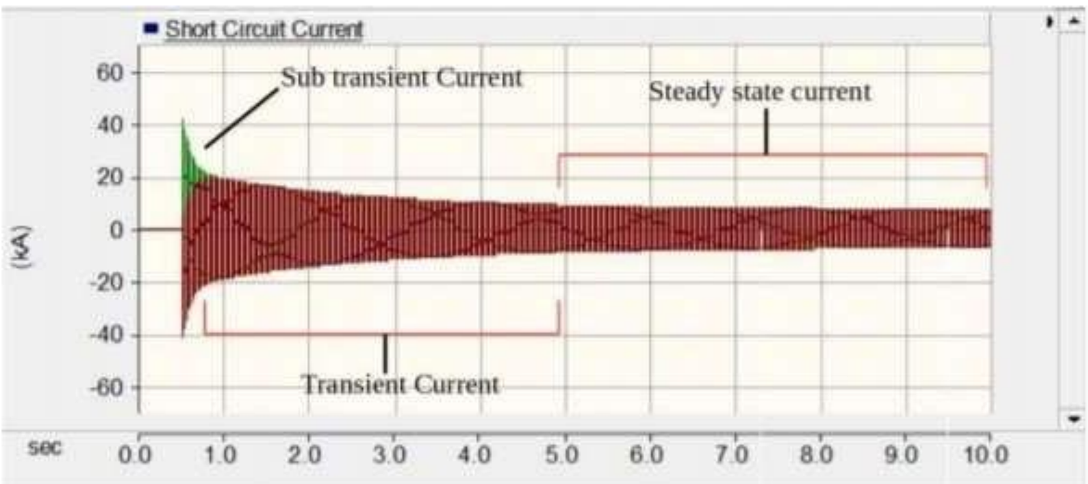

Fig. 6 Short circuit current of 5KVA Single phase synchronous generator with Salient Pole rotor (Deepthi et al, 2020).

Three stages of short circuit fault in single phase synchronous generator as shown in the diagram above. When short circuit fault occur at the generator's terminals, the armature current waveform can be divided into three distinct periods and they are the sub-transient, transient, and steady-state periods as shown in Fig 6. Each stage is characterized by a different value of the generator's internal reactance, which dictates the magnitude of the short-circuit current.

Sub – Transient

This is the initial and most violent stage, lasting for only a few cycles after the fault. The armature current reaches its maximum peak during this period. The very high rate of change of current induces currents in both the field winding and, critically, in the damper windings. These induced currents create magnetic fields that oppose the change in the main field flux, a phenomenon dictated by Lenz's Law.

The Transient Period

Following the sub-transient period, the currents induced in the low-resistance damper windings decay rapidly. However, the induced currents in the field winding, which has a much higher time constant (due to its larger inductance and resistance), persist for a longer duration.

As the influence of the damper windings wanes, the burden of opposing the armature reaction flux shifts to the field winding. This results in a higher effective reactance, termed the transient reactance (Xd′). Consequently, the armature current begins to decay from its initial high sub-transient value to a lower, but still significant, transient value. This period typically lasts for about 30 cycles.

The Steady-State Period

Finally, after the induced currents in both the damper and field windings have decayed to zero, the only opposition to the armature current is the generator's synchronous reactance (Xd). This reactance is a measure of the steady-state opposition to the armature magneto motive force (MMF) under normal operating conditions.

At this stage, the short-circuit current settles to its steady-state value, which is significantly lower than the initial fault current but can still be several times the rated current of the generator. The magnitude of the steady-state short-circuit current is determined by the synchronous reactance and the generator's internal electromotive force (EMF).

V. CONCLUSION

In this study, a sudden short circuit fault was imposed on a 5KVA single phase synchronous generator and its responses was analyzed. This analysis of sudden short circuit fault in this generator reveals the critical impact such disturbances can have on the machine’s performance. Any time fault takes place, the generator is subjected to intense transient currents and electromagnetic forces which leads to severe mechanical stress, overheating and potential damage to the stator and rotor windings. However, having a good knowledge of a synchronous generator under sudden short circuit fault conditions is important for designing reliable power systems. Proper fault analysis allows for effective implementation of protection strategies, enhance generator longevity and maintain system stability.

REFERENCES

[1] Ahmed Al-Timimy, Paolo Giangrande, Michele Degano, and Michael Galea “ CFD Optimisation of thermal design for a vented electrical machine” Conference: 2017 IEEE Workshop on Electrical Machines Design, Control and Diagnosis (WEMDCD), 2017.

[2] B. Adkins and R.G. Harley, The General Theory Of Alternating Current Machines: Applications to Practical Problems, SpringerScience+Business Media, B.V.,1975.

[3] B. Zaker, G. B. Gharehpetian, and M. Karrari, “Improving synchronous generator parameters estimation using d–q axes tests and considering saturation effect,” IEEE Trans. Ind. Inform., vol. 14, no. 5, pp. 1898– 1908, 2018, doi: 10.1109/TII.2017.2759502.

[4] G. Gutiérrez Rodríguez, A. Silveira e Silva, and N. Zeni, “Identification of synchronous machine parameters from field flashing and load rejection tests with field voltage variations,” Electr. Power Syst. Res., vol. 143, pp. 813–824, 2017, doi: 10.1016/j.epsr.2016.08.025.

[5] Mohsen Mostafeci and Jawad Faiz “ An overview of various detection methods in synchronous generator” IET Electric power applications. Volume 15, pp 391 – 404 (2021). DOI: 10.1049/elp2.12031

[6] Nandi, S., Toliyat, H. A., & Li, X. (2005). Condition monitoring and fault diagnosis of electric motors- a review. IEEE Transactions on Energy Conversion, 719-729.

[7] Narasimhan, S., Roychoudhury, I., Balaban, E., & Saxena, A. (2010). Combining model-based and feature-driven diagnosis approachesa case study on electromechanical actuators. 21st International Workshop on Principles of diagnosis, 1 – 8.

[8] Padmanabhan Sampath Kumar, Yejin Chen, Meng Yeong Lee , Sivakumar Nadarajan , Lihua Xie " Modified Winding Function Approach to Stator Fault Modelling of Synchronous Generator" Conference paper, June, 2016. https://www.researchgate.net/publication/305674745

[9] P. Tavner, J. Penman, 1987, 'Condition Monitoring of Electrical Machines', Research studies press LTD, 1987. ISSN/ISBN: 0-86380-061-0, 302 p.

[10] Siddique, A., Yadava, G. S., & Singh, B. (2005). A review of stator fault monitoring techniques of induction motor. IEEE Transactions on Energy Conversion, 106-114.

[11] S. S. Apeshi, E. S. Obe and J. E. Akpama " Performance Analysis of Single phase interior permanent magnet synchronous generator" Nigerian Journal of Technology (NIJOTECH) Vol. 38, No. 4, October 2019, pp. 980 – 986.

[12] Toliyat, H.A., et. al.: Electric machines: modelling, condition monitoring, and fault diagnosis, 1st ed. CRC Press, Boca Raton, New York (2012) 53. Rabbi, A.: Detection of stator inter-turn fault of syn