The mitigation techniques inrush current of transformer and voltage sag compensator

Pradeep Kumar*[1], Dr. Sanjay Jain[2]

*[1] *M.Tech Student, Electrical Engineering Department, RKDF University, Bhopal, M.P.*

pradeepk9577@gmail.com[1]

[2]*HOD, Electrical Engineering Department, RKDF University, Bhopal, M.P.*

jain.san12@gmail.com[2]

Corresponding Author: Pradeep Kumar
Manuscript Received: Manuscript Accepted:

Abstract

As soon as the load voltage is restored by the compensators the flux linkage is driven to magnetic saturation level and hence a severe inrush current starts to flow. Due to this the critical load gets restricted by the voltage sag when the compensator is deferred by its won over current protection and finally the compensation goes unsuccessful. Therefore I am hereby proposing a mitigation technique for inrush current together with voltage sag compensator by the use of PI controller with it. Hereby to validate the approach the basic operating principles of the proposed methods are specially presented and simulations are also shown.

Keywords

PI controller, Inrush current, Compensator

1. ANALYTICAL ANALYSIS OF INRUSH CURRENT OF TRANSFORMER

Energization of unloaded transformers results magnetizing inrush current (IC) with high amplitude. These currents have many unfavorable effects, including operation and failure of transformer differential protection, deterioration of the insulation and mechanical support structure of windings and reduced power quality of the system. On the voltage wave producing high inrush current peak without controlled switching the energization may occur at any time, when the transformer core is driven into saturation. Power transformer is one of the vital components of electric power systems that require the protective relays with good features like very high security, dependability, and speed of operation. But the magnetizing inrush current can cause the false tripping of the differential relay as it is often generated when the transformer is energized, therefore reduction of inrush current become important. Some methods have been discussed to reduce inrush current. Pre-insertion of series resistors and synchronous closing of circuit breakers are examples of the available mitigation techniques. A neutral resistor based scheme for mitigating inrush currents was proposed in some papers.

Table 1 - Various method comparisons

Method	Positive max current (pu)	Negative min current (pu)
Normal	5.96	-5.24
A. With pre-resistor	5.05	-4.91
B. With capacitor	4.95	-4.2
C. Capacitor& pre- resistor	4.19	-3.82
D. Auxiliary load	4.78	-2.39
E. Auxiliary load &capacitor	3.2	-2.72
F. Auxiliary load & capacitor & pre- Resistor	2.89	-2.48
G. Best time of switching	1.08	-1.01
H. Asynchronous	1	-1

2. METHODOLOGY

Issues related to power quality have been a serious topic over past few years. Therefore the manufacturers get affected by any event of power quality in the utility grid. According to records92% of the power quality issues are caused by voltage sag, transients, and momentary interruptions. Voltage sags are the reason why the critical loads are often interspersed resulting insubstantial productivity losses. As a solution to this problem voltage sag compensators has been proved to be one of the most economic one in industries and most of the compensators are able to restore the voltage within a quarter of cycle. Nevertheless before the restoration of voltage the load transformer is released under the deformed voltages and the magnetic flux deviation is established within the load transformers. After the load voltage gets restored, the flux may deviate further beyond the saturation knee of the core and significant inrush current is the result. This inrush current can easily trigger protection of the compensator and the compensation fails. Voltage sag compensator basically has a coupling transformer which is connected is series and a three-phase voltage-source inverter. To achieve high operating efficiency under normal condition in grid the compensator is bypassed by the thyristors. The voltage sag compensator is supposed to injects the required compensation voltage through the coupling transformer when the voltage appears across the critical load to protect it from getting interspersed. Controlling phase angle or actively controlling the transformer current and the voltage magnitude are some of the techniques used to mitigate transformer inrush and many more techniques are introduced for the same. These methods are not suitable for voltage sag compensators that demands the precise point on wave restoration of the load and these methods can also effortlessly change the waveforms of output voltage of the converter. The integrated conventional closed-loop control mitigation technique on the load voltage is presented here. This integrated control can affluently mitigate the inrush current of load transformers and the robustness of the sag compensator system and disturbance rejection capability is enhanced.

2.1 phase locked loop

The basic PLL block diagram is shown in the figure below. It is basically a flip flop which consists of a phase detector, a low pass filter (LPF),and a Voltage Controlled Oscillator (VCO).

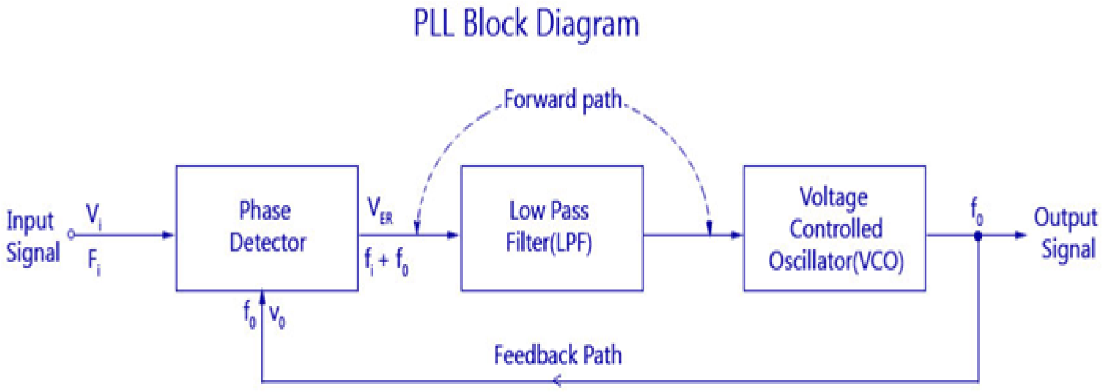

Figure 2.1Block Diagram - Phase Locked Loops

2.2 PI Controller

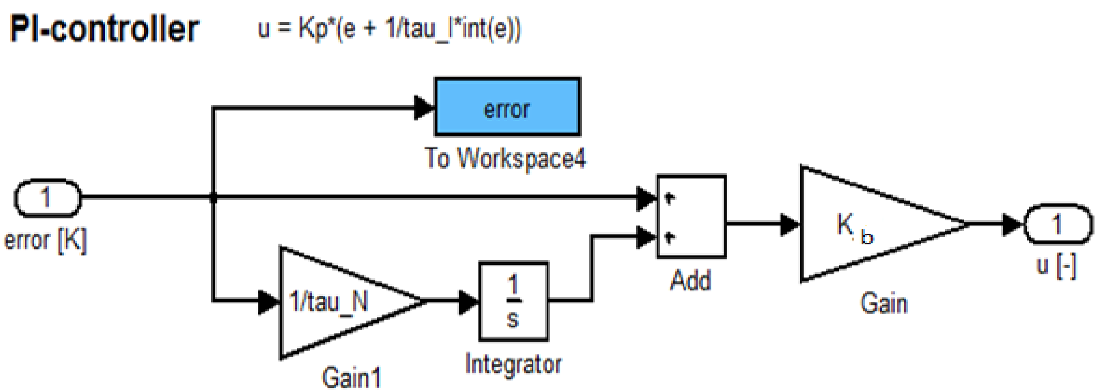

Figure 2.2 PI-controller

µ and the radiator heat would be negative when the error is negative ($t > t_{set}$)! Which is impossible, therefore a "Saturation" block have been included in the actuator block, shown in figure 3.6.3. The block is set at Max = Q_R and Min = 0.

3. SIMULATION RESULT

3.1 SIMULINK model for mitigation of inrush current

When a three phase source is connected to non linear load via transmission channel without any mitigation circuit then there are harmonics created which causes inrush current in the load transformer. It can be seen in the waveforms obtained below:

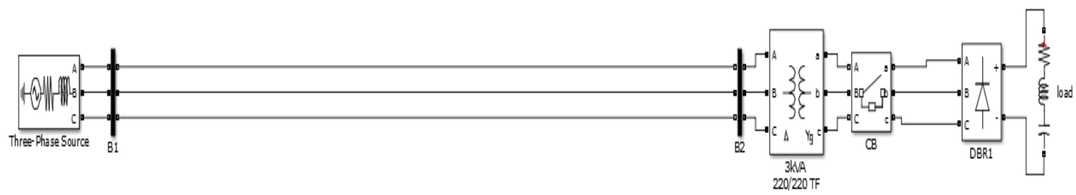

Figure 3.1SIMULINK model of transmission line connected to load without any inrush mitigation.

In the shown SIMULINK a three phase source is coupled to bus B_1 which is linked to the transmission line to a transformer which is supplying power to the non linear load through a rectifier which is converting the AC voltage to DC. A bus B2 is coupled to the load side. The three phase source is having 220 V, 60 Hz.

The waveforms of the source voltage and current are shown below.

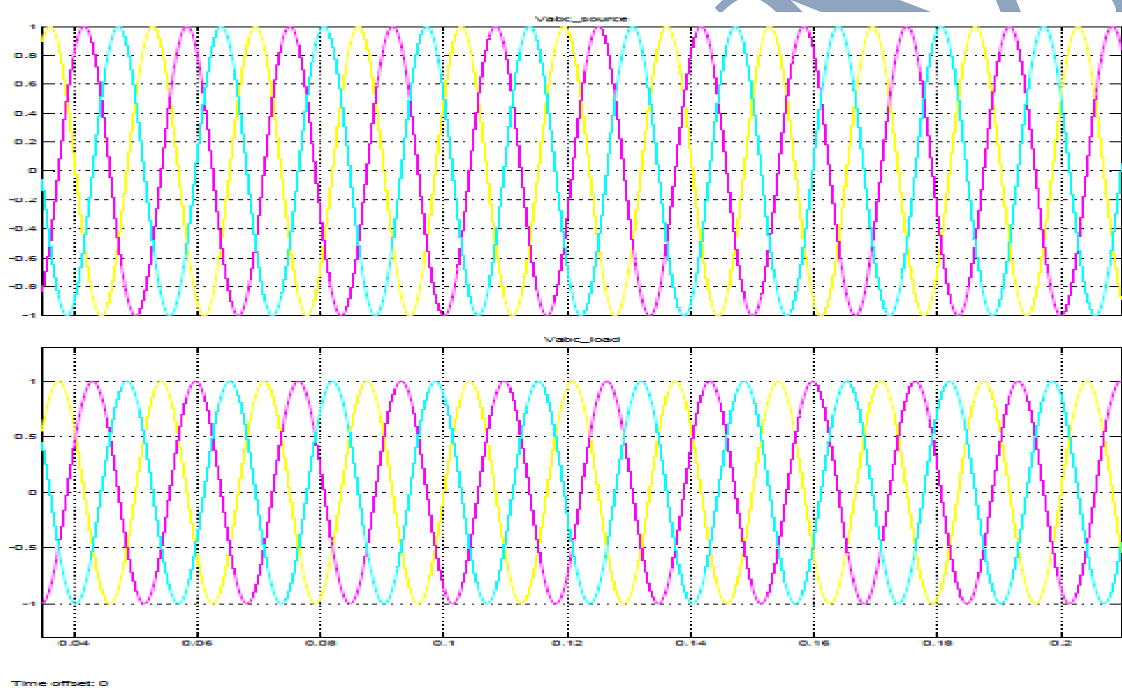

Figure 3.2.Waveform of the source & load voltage when the circuit breaker is not connected.

Once the circuit breaker is closed, non linear load gets linked to the circuit after 0.2 seconds due to which the harmonics are generated which are causing the deformation in the waveform as revealed in figure below.

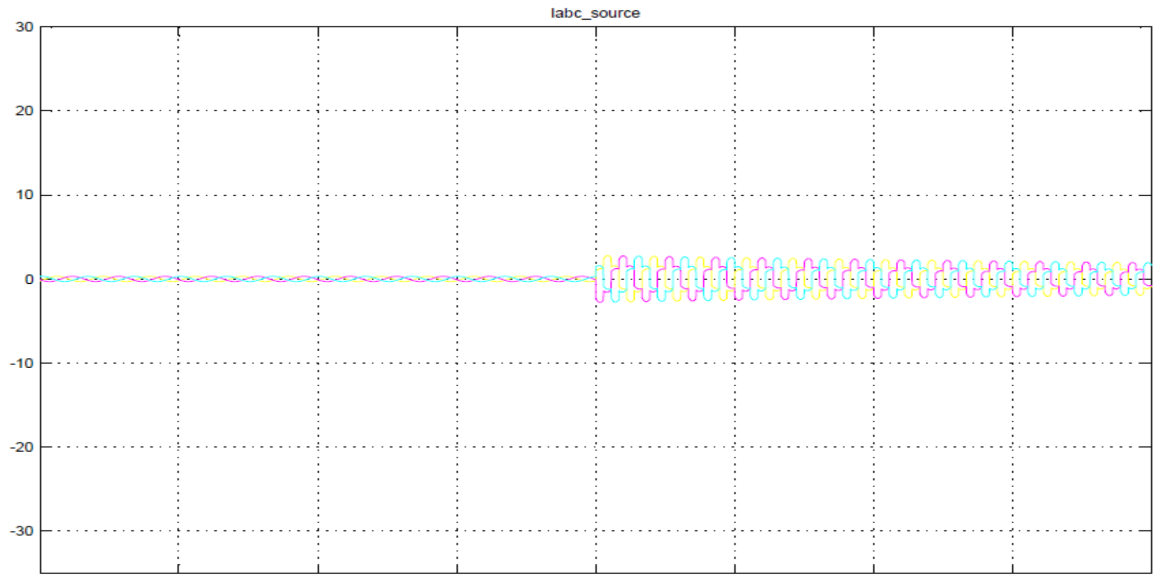

Figure 3.3.Waveform of the source current when circuit breaker is closed at 0.2 sec without mitigating inrush current.

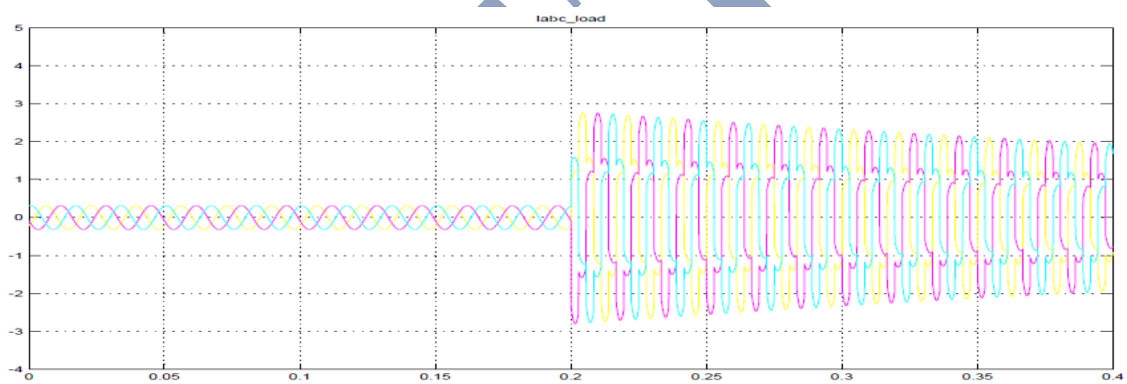

Figure 3.4.Load current waveform when circuit breaker is closed at 0.2 sec without mitigating inrush current.

REFERENCES

[1] E. H. Talbi, L. Abaali, and R. Skouri, “Optimal power flow dispatch using trust region based multiplier method,” in *Advanced Intelligent Systems for Sustainable Development (AI2SD’2019)*, M. Ezziyyani, Ed. Cham: Springer International Publishing, 2020, pp. 187–199.

[2] A. Santos and G. R. M. da Costa, “Optimal-power-flow solution by newton’s method applied to an augmented lagrangian function,” *IEE Proceedings - Generation, Transmission and Distribution*, vol. 142, no. 1, pp. 33–36, Jan 1995. doi: https://doi.org/10.1049/ip-gtd:19951586

[3] E. J. Oliveira, L. W. Oliveira, J. Pereira, L. M. Honório, I. C. Silva, and A. Marcato, “An optimal power flow based on safety barrier interior point method,” *International Journal of Electrical Power & Energy Systems*, vol. 64, pp. 977–985, 2015. doi: https://doi.org/10.1016/j.ijepes.2014.08.015

[4] L. Casacio, C. Lyra, and A. Oliveira, “Interior point methods for power flow optimization with security constraints,” *International Transactions in Operational Research*, vol. 26, no. 1, pp. 364–378, 2019. doi: https://doi.org/10.1111/itor.12279

[5] G. L. Torres and V. H. Quintana, "An interior-point method for nonlinear optimal power flow using voltage rectangular coordinates," *IEEE Transactions on Power Systems*, vol. 13, no. 4, pp. 1211–1218, Nov 1998. doi: https://doi.org/10.1109/59.736231

[6] J. Zhu, *Uncertainty Analysis in Power Systems*. John Wiley & Sons, Ltd, 2008, ch. 13, pp. 545–596. doi: https://doi.org/10.1002/9780470466971.ch13

[7] A. von Meier, *Power Flow Analysis*. John Wiley & Sons, Ltd, 2006, ch. 7, pp. 195–228. doi: https://doi.org/10.1002/0470036427.ch7

[8] T. Mühlpfordt, V. Hagenmeyer, and T. Faulwasser, "Uncertainty quantification for optimal power flow problems," *PAMM*, vol. 19,no. 1,p. e201900087, 2019. doi:https://doi.org/10.1002/pamm.201900087

[9] C. D. Zuluaga and M. A. Álvarez, "Approximate probabilistic power flow," in *Data Analytics for Renewable Energy Integration*, W. L. Woon, Z. Aung, O. Kramer, and S. Madnick, Eds. Cham: Springer International Publishing, 2017, pp. 43–53.

[10] Y. Z. Li and Q. H. Wu, "Downside risk constrained probabilistic optimal power flow with wind power integrated," *IEEE Transactions on Power Systems*, vol. 31, no. 2, pp. 1649–1650, March 2016. doi: https://doi.org/10.1109/TPWRS.2015.2412684

[11] A. Schellenberg, W. Rosehart, and J. Aguado, "Introduction to cumulant-based probabilistic optimal power flow (p-opf)," *IEEE Transactions on Power Systems*, vol. 20, no. 2, pp. 1184–1186, May 2005. doi: https://doi.org/10.1109/TPWRS.2005.846188

[12] Guangzheng Yu and Tao Lin, "2m+1 point estimate method for probabilistic harmonic power flow," in *2016 IEEE Power and Energy Society General Meeting (PESGM)*, July 2016, pp. 1–5. doi: https://doi.org/10.1109/PESGM.2016.7741657

[13] W. Lin, Z. Yang, J. Yu, S. Bao, and W. Dai, "Toward fast calculation of probabilistic optimal power flow," *IEEE Transactions on Power Systems*, vol. 34, no. 4, pp. 3286–3288, July 2019. doi: https://doi.org/10.1109/TPWRS.2019.2911050

[14] T. Shu, X. Lin, S. Peng, X. Du, H. Chen, F. Li, J. Tang, and W. Li, "Probabilistic power flow analysis for hybrid hvac and lcc-vsc hvdc system," *IEEE Access*, vol. 7, pp. 142 038–142 052, 2019. doi: https://doi.org/10.1109/ACCESS.2019.2942522

[15] D. F. Teshome and M. T. Enyew, "Linearized power flow for stochastic optimization," in *2017 IEEE 30th Canadian Conference on Electrical and Computer Engineering (CCECE)*, April 2017, pp. 1–4. doi: https://doi.org/10.1109/CCECE.2017.7946600