Enhancing Three-Phase Induction Motor Performance with Soft Ramp Control

Asif Hussain[1], Raja Masood Larik[2], Muhammad Salman Saeed[3], Agha Yasir Ali[4], Usman Humayun[5], Muhammad Rashid[1], Zain-ul-Abiden Akhtar[6], Zeeshan Ahmad Arfeen[1*]

[1]Department of Electrical Engineering, The Islamia University of Bahawalpur (IUB), 63100-Bahawalpur- Pakistan

[2]Department of Electrical Engineering, NED University of Engineering and Technology, (NEDUET), Karachi, Pakistan

[3]Multan Electric Power Company (MEPCO), Multan, Pakistan

[4]Department of Data Science and Computing, Sir Syed University of Engineering and Technology (SSUET), Karachi, Pakistan

[5]Department of Computer Engineering, Faculty of Engineering Bahauddin Zakariya University (BZU) Multan 60800, Pakistan

[6]Department of Information and Communication Engineering, The Islamia University of Bahawalpur (IUB), Bahawalpur- Pakistan

*** Correspondence:** Zeeshan Ahmad Arfeen; zeeshan.arfeen@iub.edu.pk

Citation | Hussain. A., Larik. R. M., Saeed. M. S., Ali. A. Y., Humayun. U., Rashid. M., Akhtar. Z. U. A., Afreen. Z. A., "Enhancing Three-Phase Induction Motor Performance with Soft Ramp Control" IJIST, Vol. 06 Issue. 04 pp 2117-2123, Dec 2024

Received | Nov 21, 2024 **Revised |** Dec 14, 2024 **Accepted |** Dec 19, 2024 **Published |** Dec 21, 2024.

Three-phase induction motors experience high inrush currents during start-up, exceeding their rated capacity and potentially damaging stator windings. This paper explores the implementation of soft ramp control to address this challenge. Soft starters progressively increase the voltage applied to the motor, mitigating the current surge and associated electromagnetic torque. This reduces stress on the motor shaft, and connected equipment even though preventing disruptions in the power supply network. The proposed technique aims to start the motor at a lower speed and gradually climb to its maximum rated speed. This paper employed a gentle ramp control strategy using TRIAC-based voltage regulation. This technique prevents abrupt surges that could harm the motor and related equipment. The study illustrates the soft start process for a three-phase induction motor using a prototype setup and a simulation model. The soft start technique dramatically lowers starting current, mechanical stress, and electromagnetic disturbances, improving motor health and performance, according to experimental data. This method is a cost-effective alternative for industrial applications since it not only increases motor longevity but also lowers the related power losses.

Keywords: Three-Phase Induction Motor; Soft Ramp Control; High Starting Current; Starters and Inrush Current.

Introduction:

Induction motors are being increasingly used in a variety of applications but not limited to conveyor systems, blowers, fans, traction, elevators, and pumps, amongst others. The efficiency of these systems is dependent on the performance of the induction motor, which in turn is dependent on the performance of the induction motor when it is both beginning and operating. Direct starting of induction motors, particularly those with a high horsepower rating, will result in a drop in the supply voltage, as well as heating and a fluctuation in torque. In most cases, the starting current and torque variation of an induction motor can be reduced to a minimum by decreasing the starting voltage of the motor. There are many ways, including soft starts, auto-transformer starters, star-delta starters, and reactor starters, that can be utilized to bring down the starting voltage. The soft starter is the most popular type of starter since it can reduce the starting current, is reliable, doesn't make any noise, and takes up less space than the other starters. Soft starters gradually increase the motor's power supply to prevent sudden surges, helping the motor start smoothly and safely.

As a consequence of this, the beginning current of an induction motor gradually grows. After the motor has been started successfully, the complete soft starter is bypassed with the assistance of sensors and contactors. The majority of the types of equipment used in industrial settings are induction motors with three phases. They need to have a straightforward and sturdy construction, and the fact that they are resilient makes it feasible for them to function in any setting. Additionally, induction machines have lower costs and require no maintenance. Further, they come with a commencing torque and are utilized extensively in a variety of applications, both in the home and in the industries [1] The high current can cause excessive heating and stress on the stator windings, potentially leading to insulation breakdown and motor failure [2]. The sudden increase in torque can cause mechanical stress on the motor shaft and connected equipment, leading to premature wear and tear [3]. The high current drawn can create voltage dips in the power supply network, impacting other equipment [4]. Soft starters progressively increase the voltage applied to the motor, mitigating the current surge and associated electromagnetic torque. Merits of soft ramp control for both motor health and performance are delineated as:

1. Good Health and Well Being
2. Affordable and Clean Energy
3. Decent Work & Economic Growth
4. Industry, Innovation and Infrastructure
5. Sustainable Cities & Communities
6 Climate Action

Objectives of Study:

- To lower high starting currents in three-phase induction motors.
- To examine how this affects performance indicators like torque and efficiency.

Novelty Statement:

In contrast to conventional techniques, this study presents an optimized soft ramp control mechanism that integrates TRIAC-based voltage regulation for smoother start-ups, lowering mechanical stress and electromagnetic disturbances.

Literature Works:

The authors in [5][6] demonstrated how soft ramp control effectively limits the inrush current during start-up, protecting the motor windings and power supply network. Studies by [7][8] highlighted that smooth start reduces mechanical stress on the motor and shaft, directing to improve motor longevity and efficiency. Research by [9] explored how soft ramp control method allows for smoother torque control during start-up and acceleration, minimizing mechanical shocks to connected equipment. Solid-State Soft Starters utilize thyristos or TRIACS to control the voltage applied to the motor during start-up. The authors in [10] analyzed the design and operation standards of the TRIAC-based soft starters, highlighting how they regulate the firing angle to achieve a gradual voltage ramp-up.

The TRIAC can switch heavy currents rapidly, allowing the soft starter to provide a smooth, step-less acceleration of any soft start method. Generally, Mechanical vibrations and excessive electrical stress on the motor windings can cause the coils to overheat and eventually burn out [11]. Some demerits are:

- It draws an excess amount of current than its rated value.
- It causes the shocks in the system.
- It leads to a decrease in power factor.
- In the reference paper [12], the authors maintained the inrush current and torque pulsations in the induction motor drives by the soft switching technique during the start of the motor. Jahić, Hederić [11], discussed the problems with high-voltage induction motor rotor failures, their causes, and ways to find them.

Methodology:

Figure 2 illustrates the simulation model used to model the soft start of the 3-phase induction motor, while Figure 1 displays the flow diagram of the proposed model. The waveforms of the model were observed using a Cathode Ray Oscilloscope (CRO).It demonstrates fluctuations in power, voltage variations, and current changes in the prototype for the smooth starter of the induction motor. The circuit schematic was implemented using the following components, and the prototype has been examined concerning its capacity to support the load of the bulb [13].

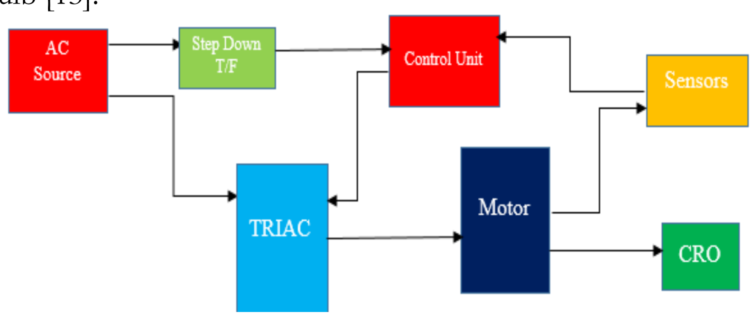

Figure 1. Flow chart of the complete proposed model.

The equations for induction motors are as follows:

$$\frac{di_\alpha^s}{dt} = \frac{1}{L_s}u_\alpha^s - \frac{R_s}{L_s}i_\alpha^s - \frac{M}{L_s}\frac{di_\alpha^r}{dt} \quad (1)$$

$$\frac{di_\beta^s}{dt} = \frac{1}{L_s}u_\beta^s - \frac{R_s}{L_s}i_\beta^s - \frac{M}{L_s}\frac{di_\beta^r}{dt} \quad (2)$$

$$\frac{di_\alpha^r}{dt} = \frac{R_r}{L_r}i_\alpha^r - \frac{M}{L_r}\frac{di_\alpha^s}{dt} - \omega_r i_\beta^r - \omega_r\frac{M}{L_r}i_\beta^s \quad (3)$$

$$\frac{di_\beta^r}{dt} = \frac{R_r}{L_r}i_\beta^r - \frac{M}{L_r}\frac{di_\beta^s}{dt} - \omega_r i_\alpha^r - \omega_r\frac{M}{L_r}i_\alpha^s \quad (4)$$

where: i_α^s and i_β^s are the stator currents, i_α^(r,) and i_β^r are the rotor currents, u_α^s and u_β^s= Stator voltages. u_α^r and u_β^r= Rotor voltage M = Lm: Constant of mutual induction. R_r=Rotor resistance. R_s=Stator resistance. L_s= Stator inductance. L_r= Rotor inductance. ω_r= Angular velocity, (di_α^s)/dt&(di_β^s)/dt= Rate of change of stator currents, (di_α^r)/dt& (di_β^r)/dt = Rate of change of rotor currents.

The torque & speed equations are as computed as: $T_{em} = \frac{3}{2}\rho M\left(i_\beta^s i_\alpha^r - i_\alpha^s i_\beta^r\right)$ (5)

$$\frac{d\omega_r}{dt} = \frac{P}{J}(T_{em} - T_m) \quad (6)$$

where: T_m= load torque. P= number of pairs of poles. J= moment of inertia. T_em= electromagnetic torque. ω_r= angular velocity.

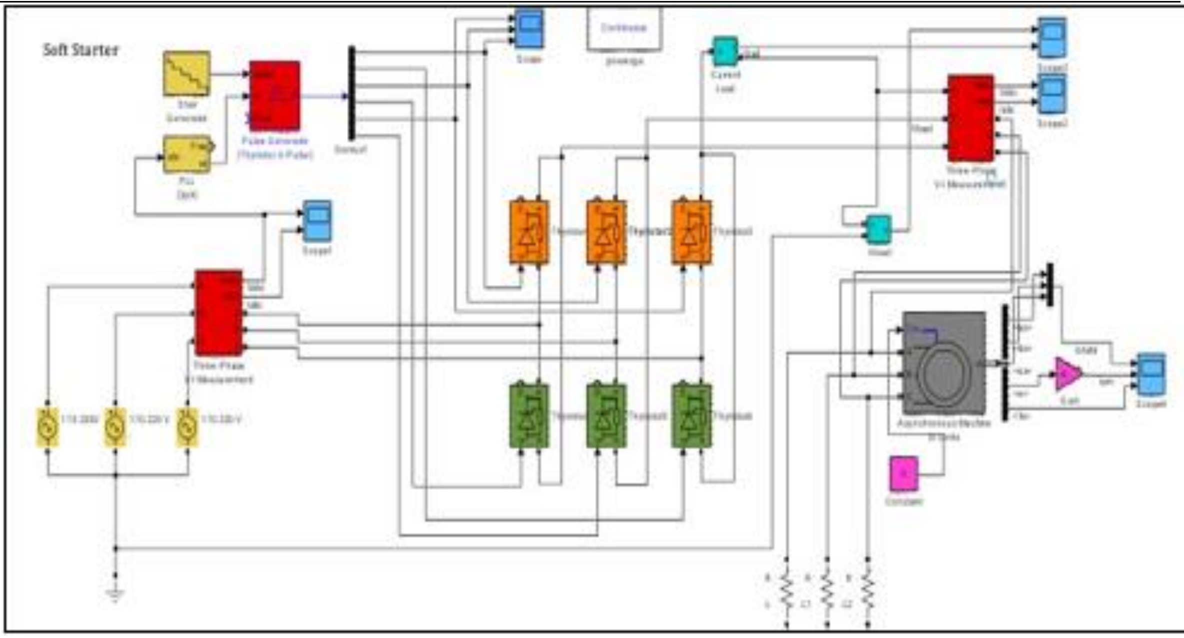

Figure 2. Simulation model for soft start of 3-phase induction motor.

Table 1 comprises all of the necessary information i.e. name of component used, rating of component, and number of components. It shows that TRAIC (BTA16), Diode (1N4007), and Transformer (220-12 V) were used for this research. Six (6) bulbs were utilized in this study for load.

Table 1. Details of components used in hardware.

Sr #	Name of component used	Rating of component	Number of components
1	LCD	16*2	1
2	Arduino	Uno	1
3	TRAIC	BTA16	3
4	OPTO Coupler	MOC 3021	1
5	OPTO Coupler	PC 817	1
6	Buck Converter	LM2596	1
7	Diode	1N4007	3
8	Transformer	220-12 V	3
9	Bulb	40W	6

Results & Discussions:

By employing the necessary module supply and correctly arranging it, we successfully implemented the soft starter for the three-phase induction motor. This was accomplished by positioning the modules as given in Figure 3.

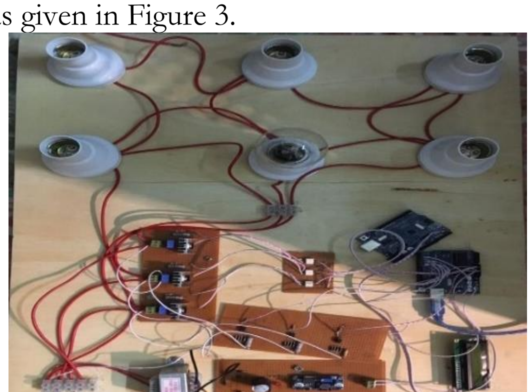

Figure 3. Physical representation of the complete model.

The IM speed in rpm and initial current of the motor was effectively supervised by the controller. The program was successfully encrypted in regulating the current and the situation corresponded to the rated value of the motor windings. The IM "soft start" was tested and successfully deployed. This type of soft starting is carried out immediately after the trigger has been turned on, and it is coupled to the state of the parallel-connected TRIACs in each phase. The amplifier trigger approach is responsible for activation. After comparison, it was determined that the current-limiting process used in the soft start method is far more effective than those in the Direct Online (D.O.L.) starter and the star-delta starter. Figure 4 represents the IM speed in rpm. At Y-axis the Induction Motor Speed (RPM) is shown and, the y-axis is labeled from 0 to 2000 RPM in steps of 500. The X-axis represents the time (seconds) and the x-axis is labeled from 0.2 to 0.8 with an increment of 0.1.

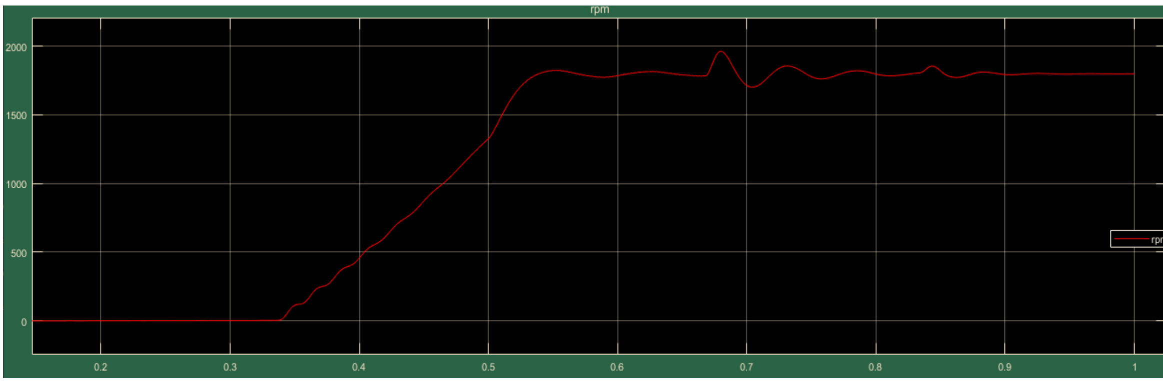

Figure 4. Speed of the Motor in (rpm).

The stator current versus time is displayed in Figure 5. It presents the waveform of stator current plotted against time, illustrating the dynamic variation of the current over the motor's operating cycle. The transient response, such as inrush current at motor startup and its gradual decrease to a steady-state value, is clearly observable.

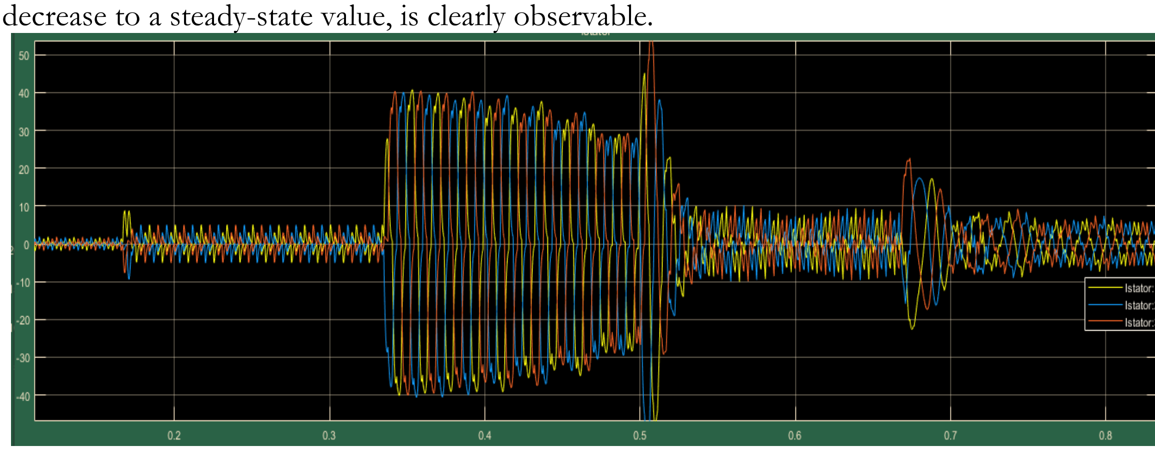

Figure 5. Complete waveform of the stator current.

By adjusting the trigger angle of the TRIAC, the amount of current limiting versus time that was achieved is shown in Figure 6.

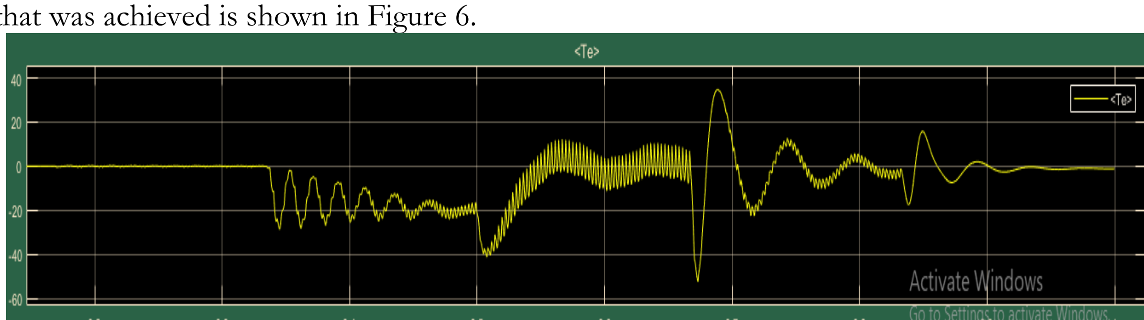

Figure 6. Current limiting waveforms of the proposed model.

Conclusion:

This paper presented a compelling case for implementing soft ramp control in three-phase induction motors. This method effectively addresses the challenges associated with high starting currents, with large quantity benefits. The controlled voltage ramp-up significantly minimizes the inrush current during start-up, protecting the motor windings and the power supply network. Soft ramp control allows precise control over the electromagnetic torque during motor acceleration. This eliminates the torque pulsations typically experienced during conventional starts, minimizing mechanical stress on the motor shaft and connected equipment. Research has shown that soft starters can significantly reduce heating losses during motor start-up, further enhancing motor efficiency and longevity. While the initial cost of a soft starter might be higher, its contribution to safety outweighs the financial considerations. Therefore, considering the long-term economic benefits of increased motor longevity and the importance of safe operation, a soft starter emerges as the superior choice for starting three-phase induction motors.

Author Contributions:

Conceptualization, Arfeen Z.A., Hussain. A. and Rashid. M.; methodology, Arfeen; Akhtar Zain., Hussain. A., Salman Saeed; software, Larik R.M, Yasir Ali A.; validation, Hussain. A., Rashid. M.; writing—original draft preparation, Hussain A, Rashid. M.; writing—review and editing, Salman Saeed, Zain Akhtar; supervision, Arfeen Z.A., Humayun U.; project administration, Humayun U., Larik R.M. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest:

The authors declare no conflict of interest.

Acknowledgments:

The scholars like to thank the Department of Electrical Engineering, The Islamia University (IUB) for the necessary support in the completion of the work.

References:

[1] Patil, M et al., "Soft Start of 3 Phase Induction Motor Using SCR," *Int. J. Innov. Res. Sci. Eng. Technol.*, vol. 10, no. 4, pp. 3778–3782, 2021.

[2] A. Nied, J. De Oliveira, R. De Farias Campos, R. P. Dias, and L. C. De Souza Marques, "Soft starting of induction motor with torque control," *IEEE Trans. Ind. Appl.*, vol. 46, no. 3, pp. 1002–1010, May 2010, doi: 10.1109/TIA.2010.2045335.

[3] Jolhe, S. et al, "Soft Starting Of Three Phase Induction Motor," *Int. Res. J. Mod. Eng. Technol. Sci.*, vol. 4, no. 4, pp. 2405–2408, 2022, [Online]. Available: https://www.irjmets.com/uploadedfiles/paper/issue_4_april_2022/21921/final/fin_irjmets1651673014.pdf

[4] O. . Obi, "Implementation of Soft Starter Using 4 Phase Induction Motor Odigwe Fidelis Obi," *African Sch. J. African Sustain. Dev.*, vol. 18, no. 2, pp. 263–268, 2020, [Online]. Available: https://www.africanscholarpublications.com/wp-content/uploads/2021/01/AJASD_Vol18_No2_Sept_2020-22.pdf

[5] P. and B. S. Dorji, "DQ Mathematical Modelling and Simulation of Three-Phase Induction Motor for Electrical Fault Analysis," *Int. Adv. Res. J. Sci. Eng. Technol.*, vol. 7, no. 9, pp. 38–46, 2020, doi: 10.17148/IARJSET.2020.7909.

[6] S. Madanzadeh, S. S. H. Bukhari, and J. S. Ro, "Multifunctional grid-connected voltage source inverter to drive induction motor operating with high-inertia load," *IEEE Access*, vol. 8, pp. 196765–196774, 2020, doi: 10.1109/ACCESS.2020.3034805.

[7] Y. Zhukovskiy, A. Buldysko, and I. Revin, "Induction Motor Bearing Fault Diagnosis Based on Singular Value Decomposition of the Stator Current," *Energies 2023, Vol. 16, Page 3303*, vol. 16, no. 8, p. 3303, Apr. 2023, doi: 10.3390/EN16083303.

[8] N. D. Kohls, R. Balak, B. P. Ruddy, and Y. C. Mazumdar, "Soft Electromagnetic Motor

and Soft Magnetic Sensors for Synchronous Rotary Motion," *https://home.liebertpub.com/soro*, vol. 10, no. 5, pp. 912–922, Oct. 2023, doi: 10.1089/SORO.2022.0075.

[9] M. Puka, A. Bardhi, A. Pjetri, and A. Mucka, "Diagnostics of Damage to the Rotor of an Induction Machine Using the Method of Instantaneous Power Analysis," *Qubahan Acad. J.*, vol. 4, no. 1, pp. 150–166, Feb. 2024, doi: 10.48161/QAJ.V4N1A263.

[10] T. and F. O. Aika, "Solid–State Current Limiting Star–Delta Starter for A 3-Phase Squirrel Cage Induction Motor," *J. Sci. Technol. Res.*, vol. 3, no. 4, pp. 367– 375, 2021.

[11] and M. A. Jahić, A., Ž. Hederić, "Detection of failures on the high-voltage cage induction motor rotor," *Int. J. Electr. Comput. Eng. Syst.*, vol. 6, no. 1, pp. 15–21, 2015, [Online]. Available: https://ijeces.ferit.hr/index.php/ijeces/article/view/828

[12] B. P. Ganthia, L. Ray, P. Senapati, and S. K. Barik, "Simulation of three phase voltage controlled soft switching start of induction motor drive," *Int. J. Recent Technol. Eng.*, vol. 8, no. 3, pp. 8104–8116, Sep. 2019, doi: 10.35940/IJRTE.C6441.098319.

[13] S. S. Nandankar, P.V., and A. Rathod, "Soft Starter for Three Phase Induction Motor," *Int. J. Latest Eng. Sci.*, vol. 3, no. 2, pp. 5–9, 2020, [Online]. Available: https://www.ijlesjournal.org/2020/volume-3 issue-2/ijles-v3i2p102.pdf