Electrical Characteristics Inspection of Multiple PV Modules for Manufacturing Industry

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Abstract: This paper presents implementation of a real time system for inspection of electrical characteristics of multiple PV modules for quality inspection in PV module manufacturing industry. PV module may have manufacturing defects which affect the I-V characteristics. In this work an experiment is performed in which multiple PV modules are kept in sunlight for inspection of I-V characteristics for a day, their open circuit voltage and short circuit current are monitored from a distant node and displayed on computer screen. The measurements are taken after fixed intervals. Relay connected across PV module is switched ON and OFF to measure short circuit current and open circuit voltage. The measured electrical characteristics are monitored from distant. The characteristics are compared with known standard values and graph is displayed on workstation for examination. The system developed in this experiment offers several advantages like 1) it provides facility to online monitor the characteristics of multiple PV modules and compares it with standard characteristics 2) focus is on automation hence less human intervention is required and 3) facility of inspection of multiple PV modules simultaneously is provided in this work.

Keywords: PV module electrical characteristics examination, IoT based PV module monitoring, PV module faults, PV module I-V characteristics monitoring

(Article history: Received:12th April 2022 and accepted 30th December 2022)

I. INTRODUCTION

Nowadays solar photovoltaic power systems are implemented in large number of applications. Due to this the demand of PV modules has increased to great extent. Considering the next trend of renewable energy systems, there is more demand of PV modules. Literature suggests that there are chances of fault in PV module which directly affects its I-V characteristics. After manufacturing PV modules they go under several examinations. There are several techniques for electrical parameter assessment of PV module like simulation based techniques, exposure of PV module to artificial UV light, manual observation etc. In this manuscript a system is developed and described for electrical characteristics check of PV modules required to be done for quality assessment.

Due to the manufacturing defect in any PV module the I-V characteristics changes and does not match with the standard PV module, the literature describing the faults in PV module is discussed here. Effect of selected faults on I-V characteristics of PV module are described in [1] , authors have reported that fault signature is associated with every fault and occurrence of fault reduces the electrical parameters of PV module. Certain faults in PV module like yellowing, browning, bubbles, cracks in cell, delamination, breakdown etc. are discussed in [2]. Various faults in solar cell are described [3]. ECM and TDR based methods for fault detection in PV system are presented [4]. Reference 5 described typical areas of fault in PV module which are solar cells/ wafer, glass base, encapsulation, internal wiring, amorphous layers etc. Authors also have described some common faults like micro-crack, adhesion failure, acetic acid generation, hot spots, sheet defects, joint damage etc. Cell open circuit and cell short circuit faults in PV module are discussed in [6]. The IoT applications are increasing and it's being used in renewable energy monitoring also. The work to monitor the electrical characteristics of PV module by means of IoT technology is done by few researchers. The system is developed [7] in which electrical parameters of PV module and environmental parameters are remotely observed via IoT platform. The applications of IoT in renewables energy systems are presented in [8]. IoT and GUI based system is developed [9] to remotely monitor the PV electrical parameters, insolation and temperature. An IoT based system for monitoring the PV station condition remotely is presented [10] which informs about the nature of fault in system to remote node for certain decision making. The PV modules suffers due to defects like open circuit, degradation, cracks, shading etc. which results in decrease in run time power, therefore authors [12] have expressed the need of continuous condition monitoring in run time. For this purpose review of various machine learning based methods are presented. According to author's deep learning, knowledge based learning and conventional ML are good tools for PV monitoring applications [12]. In ref. [13] short circuit current of PV array is continuously monitored to predict the fault. Based on the SC current the health of the PV modules is classified as healthy module, lower faulty module, medium faulty module and higher faulty module. Wireless sensor network is designed for fault monitoring of individual PV modules [14], in this the voltage of PV module is monitored to determine the faulty PV module.

The remote monitoring facility is also made available. The online health monitoring scheme for PV modules is presented [15]. A system is developed [16] to monitor the health of PV module in which the PV voltage and current are monitored through CC3200 microcontroller. The system is facilitated with WiFi and wireless communication system. Probabilistic neural network technique is used for health monitoring of PV module [17] to detect SC and OC faults in PV module. The model developed here works accurately for various temperatures. Wavelet packet based technique is described to detect the PV faults [18]. A system is developed [19] in which Hall Effect based sensors are used to monitor the PV voltage and current, through ZigBee network V & I values of PV modules are passed to Data gateway and to server. The thermal imaging technique is used to detect the faults in PV module [20], authors have reported that soil deposition, and bird waste deposition etc. increases the temperature of PV module. The electrical power of PV array is monitored remotely [21], the data is transmitted to cloud. The hotspot and PID (potential Induced Degradation) fault in PV modules is detected earlier and the information is transmitted via IoT technology [22]. The Raspberry Pi based system is developed [23] in which PV voltage, PV current and ambient temperatures are monitored and sent to cloud. For temperature monitoring the thermocouple sensor and Adafruit amplifiers are used. In reference [24] a system is developed to monitor the PV voltage and current, the monitored data is passed to cloud using IoT technology. In case of series connection of PV modules the total power decreases in shading condition, hence an algorithm is proposed to give give good performance in shading condition [25]. A mathematical model is developed to study the total power degradation in PV modules [26]. The performance of PV cells is studied for shading conditions [27]. In ref. [28] an algorithm is described to find out the unknown parameters of PV module.

Considering the defects and quality assurance of PV modules, this work is an attempt to develop the system to test the electrical characteristics of PV module against atmospheric conditions and to determine whether their I-V characteristics match with the standard one or not. This paper focuses on development of an experimental setup for quality department in PV manufacturing industry to remotely monitor the electrical characteristics of multiple PV modules; also it provides the facility of comparing the parameters with known values of standard PV module, so that defective PV modules can be traced and isolated in inspection stage.

II.SYSTEM DESIGN AND IMPLEMENTATION

This section describes the design and implementation issues of the presented system.

Figure 1 shows the system block diagram in which each PV module is connected to relay (shown as switching circuitry in figure 1), sensors for sensing PV SC current and OC voltage; and signal conditioning circuitry. The microcontroller based central controller monitors atmospheric temperature, humidity, insolation, PV SC current and OC voltage at fixed intervals and stores it in permanent memory. The central controller compares electrical parameters with known standard values.

Abnormality in electrical parameters is detected by the controller; the received data is organized in proper order and is sent to the work station. The data of each PV module is recorded and appropriately organized in memory. The technician working at workstation observes and record data in graphical form. The I-V characteristics of defective module deviates which can be seen on work station.

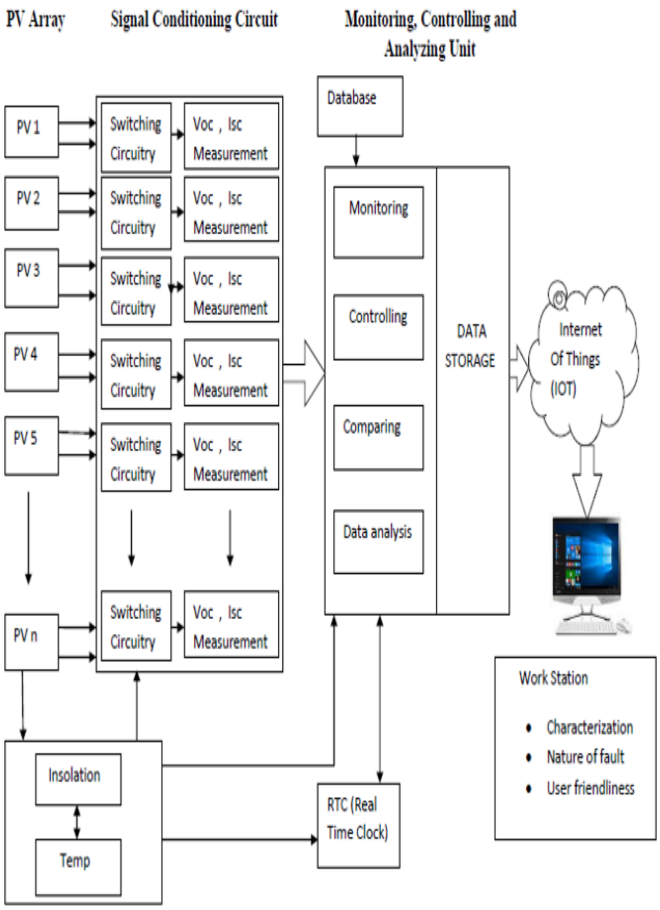


Fig.1. System block diagram

Generally PV module's SC current is measured by shorting two terminals of PV and its open circuit voltage is measured across it's terminals with no load connected. In this experiment automatically the PV SC current and OC voltage measurement is facilitated by using relay as shown in figure 2. Relay is connected across PV module, PV SC current is measured by switching the relay ON while OC voltage is measured by switching the relay OFF. In both cases the resistance of relay is considered for measurement. Relay L90CSDC24V is used for switching. Resistive voltage divider network is used to measure PV OC voltage while ACS 712 module is used for SC current measurement. OPAMP based signal conditioning circuitry is designed to process the analog signals of PV voltage and current. Entire system is developed using Arduino Mega 2560, it monitors and regulates all activities.

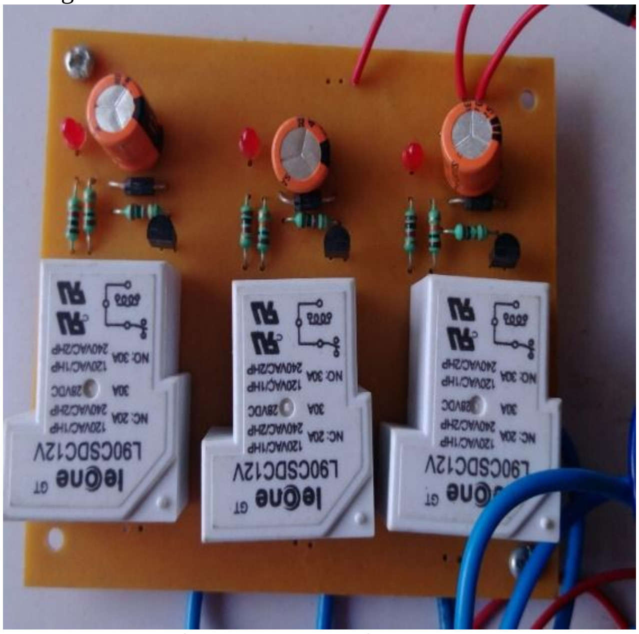


Fig.2. Relays interfaced to PV module for Isc and Voc measurement

Figure 3 shows prototype developed in laboratory. For experimentation purpose three PV modules are considered and their characteristics are compared with the characteristics of standard PV module. The PV module terminals are connected to connector as shown in figure 3.

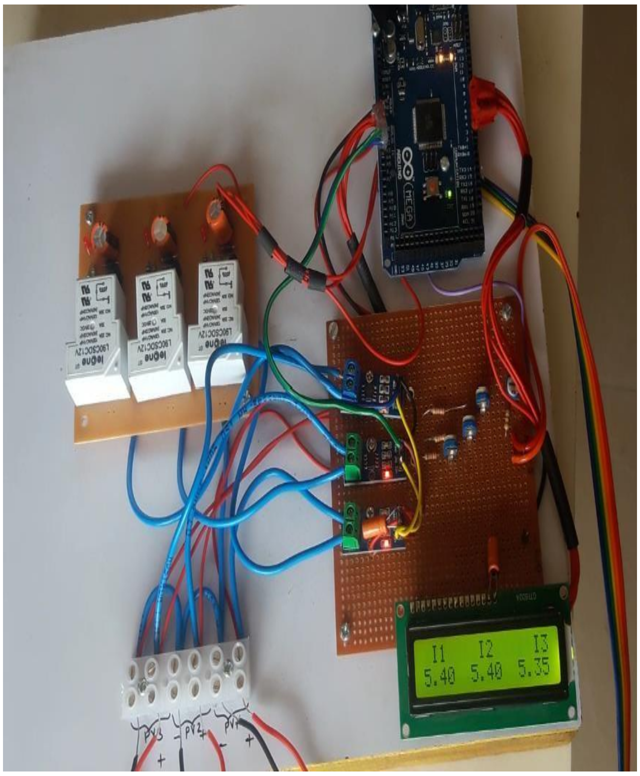


Fig. 3. System prototype developed in laboratory

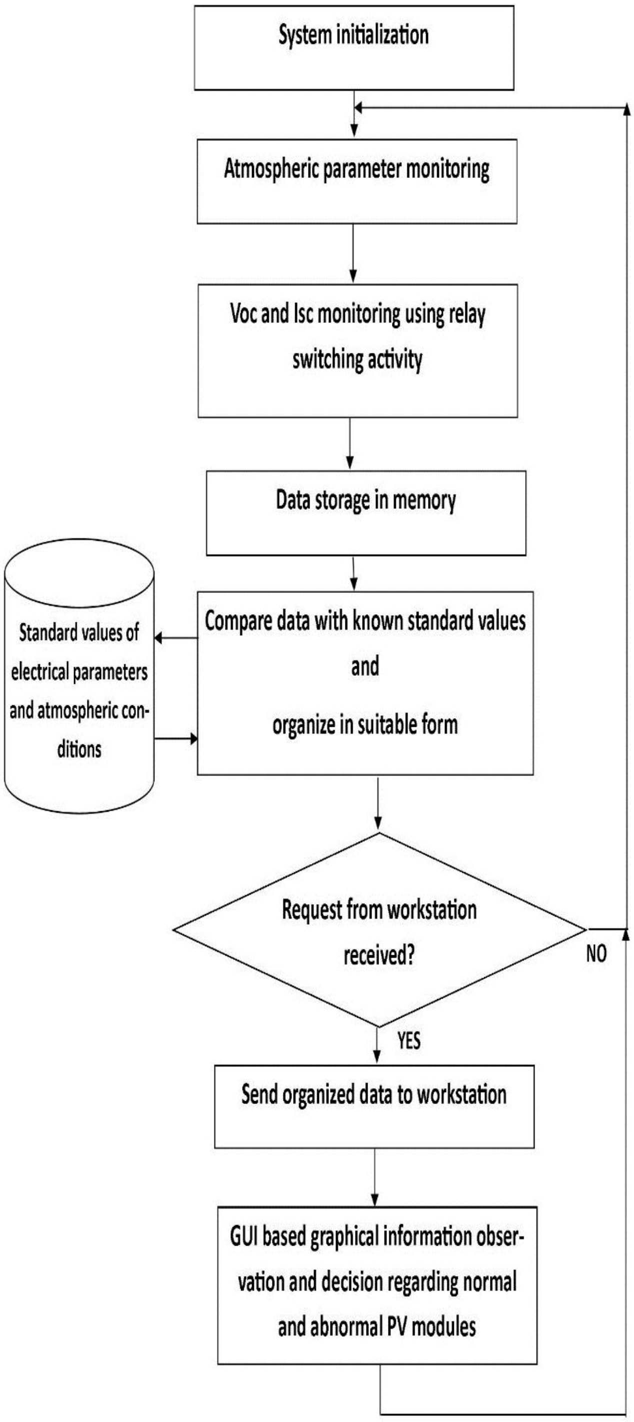


Fig. 4. System flow chart

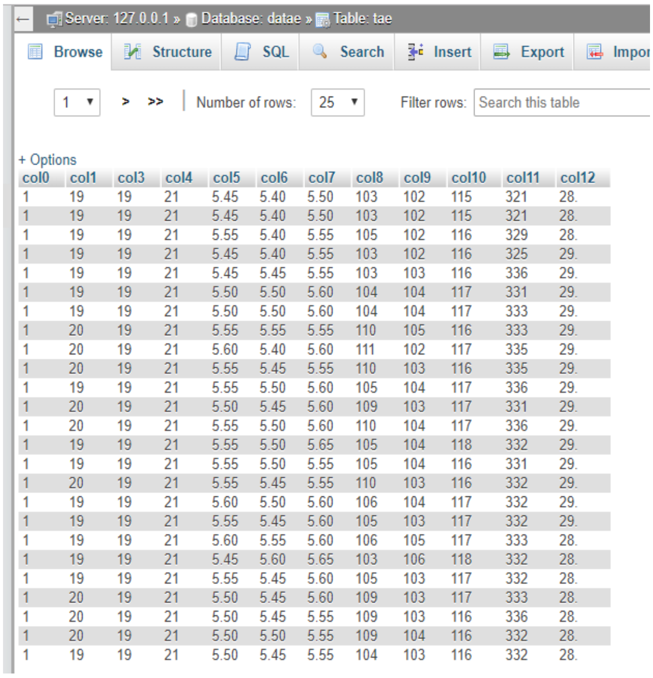
As shown in flow chart in figure 4 the microcontroller monitors the insolation, temperature and humidity, it switches ON and OFF the relays connected across PV modules and measures I_{SC} and V_{OC} after fixed intervals. It stores the data in memory and compares with the known standard values of atmospheric parameters and electrical parameters which are stored earlier. The characteristics of PV module closely following these standard values are considered as normal and PV modules whose characteristics are deviating can be considered as abnormal. The data can be accessed via workstation remotely. A typical layered structure of this application is shown in figure 5. XAMPP server facilities are used here which are open source [11].

Application Layer	1.Supervision 2.Data analysis 3.Comparison and decision making 4.Maintenance
Network Layer	1.Protocols and intermediate interfaces
Sensing Layer	1.PV module 2.Current and voltage sensors 3.Relay 4.Data base 5.Microcontroller

Fig. 5. Typical layered structure of system

III RESULTS AND DISCUSSIONS

Appearance of the screen on workstation can be seen in figure 6.



col0	col1	col3	col4	col5	col6	col7	col8	col9	col10	col11	col12
1	19	19	21	5.45	5.40	5.50	103	102	115	321	28.
1	19	19	21	5.45	5.40	5.50	103	102	115	321	28.
1	19	19	21	5.55	5.40	5.55	105	102	116	329	28.
1	19	19	21	5.45	5.40	5.55	103	102	116	325	29.
1	19	19	21	5.45	5.45	5.55	103	103	116	336	29.
1	19	19	21	5.50	5.50	5.60	104	104	117	331	29.
1	19	19	21	5.50	5.50	5.60	104	104	117	333	29.
1	20	19	21	5.55	5.55	5.55	110	105	116	333	29.
1	20	19	21	5.60	5.40	5.60	111	102	117	335	29.
1	20	19	21	5.55	5.45	5.55	110	103	116	335	29.
1	19	19	21	5.55	5.50	5.60	105	104	117	336	29.
1	20	19	21	5.50	5.45	5.60	109	103	117	331	29.
1	20	19	21	5.55	5.50	5.60	110	104	117	336	29.
1	19	19	21	5.55	5.50	5.65	105	104	118	332	29.
1	19	19	21	5.55	5.50	5.55	105	104	116	331	29.
1	20	19	21	5.55	5.45	5.55	110	103	116	332	29.
1	19	19	21	5.60	5.50	5.60	106	104	117	332	29.
1	19	19	21	5.55	5.45	5.60	105	103	117	332	29.
1	19	19	21	5.60	5.55	5.60	106	105	117	333	28.
1	19	19	21	5.45	5.60	5.65	103	106	118	332	28.
1	19	19	21	5.55	5.45	5.60	105	103	117	332	28.
1	20	19	21	5.50	5.45	5.60	109	103	117	333	28.
1	20	19	21	5.50	5.45	5.55	109	103	116	336	28.
1	20	19	21	5.50	5.50	5.55	109	104	116	332	28.
1	19	19	21	5.50	5.45	5.55	104	103	116	332	28.

Fig. 6. Data observed on workstation

Continuous values of V_{OC}, I_{SC}, insolation, temperature etc. of every connected PV module are recorded and it appears as shown in figure 6. The gathered information is categorized according to number of PV modules under observation. The graphical view of electrical characteristics of PV modules is shown in figures 7, 8 and 9. The closeness of characteristics between the module under test and the standard module can be observed in figures.

Table 1- Validation of PV module parameters

PANEL 1				PANEL 2				PANEL 3			
SYSTEM READING		MULTIMETER READING		SYSTEM READING		MULTIMETER READING		SYSTEM READING		MULTIMETER READING	
Voc	Isc	Voc	Isc	Voc	Isc	Voc	Isc	Voc	Isc	Voc	Isc
19	6.9	19	6.9	18	4.5	18	4.5	18	4.5	18	4.5
19	5.7	19	5.7	18	5.6	18	5.6	18	5.8	18	5.8
20	6.9	20	6.9	19	5.8	19	5.8	19	5.8	19	5.8
18	5.7	18	5.7	20	5.8	20	5.8	20	5.7	20	5.7
19	6.9	19	6.9	20	6.9	20	6.9	20	5.7	20	5.7
19	5.8	19	5.8	19	6.9	19	6.9	19	5.7	19	5.7
19	6.8	19	6.8	20	6.9	20	6.9	20	5.7	20	5.7
19	6.8	19	6.8	19	6.9	19	6.9	19	5.7	19	5.7
19	6.9	19	6.9	19	6.9	19	6.9	19	6.9	19	6.9
20	6.9	20	6.9	19	6.9	19	6.9	19	6.8	19	6.8

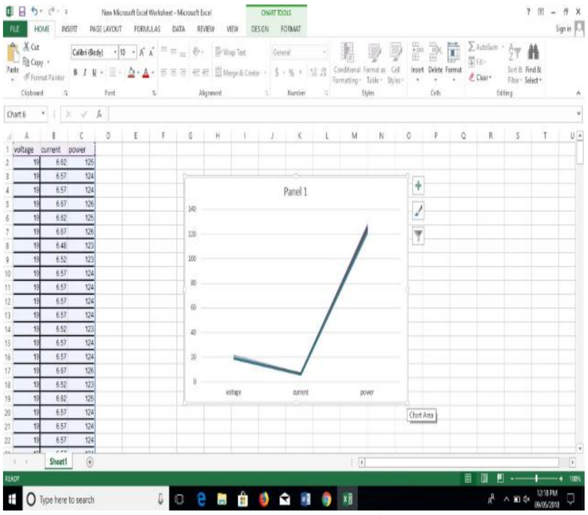


Fig. 7. Characteristics of PV module 1

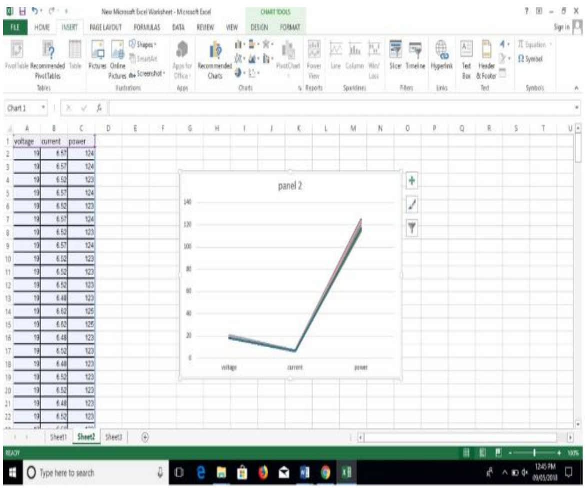


Fig. 8. Characteristics of PV module 2

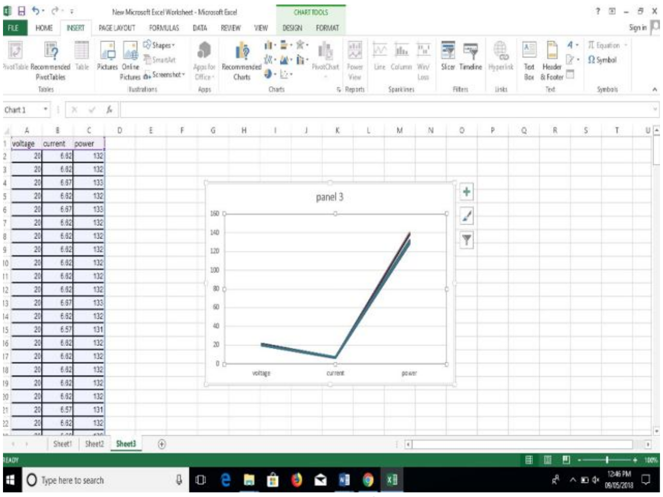


Fig.9. Characteristics of PV module 3

IV CONCLUSIONS AND FUTURE WORK

The experimentation has shown that characteristics assessment of PV panels can be done remotely by keeping the panels under test in the sunlight. Just one operator sitting at remote node can perform this task. Several PV modules can be monitored over required period of time in parallel. Further the possible prediction of the faults in PV modules can be done in real time, for this the database regarding the faults in PV modules is required.

The work can be extended further on large number of PV modules with correct database of PV module faults and deviation in I-V characteristics. This will reduce lot of manual work and will speed up the quality control process.

ACKNOWLEDGEMENT

Authors of this research work are thankful to embedded systems and VLSI Design laboratory of Department of Technology, Shivaji University, Kolhapur for providing necessary resources to accomplish this work.

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