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Experimental Measurements of Four Parallel-Connected Three-Phase Inverters of Railway Auxiliary Converters

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Abstract In this paper, experimental measurements of four parallel-connected three-phase inverters of railway auxiliary converters were carried out. The purpose of this measurement was to verify the ability of parallel co-operation of four three-phase inverters connected to a common three-phase bus, verifying the starting sequence of the inverters and power sharing by individual converters. The converters were powered by a common high voltage AC source and the outputs were interconnected to form a common three-phase network. The ability to uniform power sharing was tested during 15 kW and 137 kW motor acceleration. The results showed that all inverters were able to synchronize and connect to the common bus and stable operate in parallel connection. Furthermore, the power sharing was uniform and stable under these conditions.

Keywords parallel connection, three-phase inverters, measurement

JEL L62, L92

1. Introduction

In railway auxiliary converters, parallel co-operation of multiple inverters is required to meet the increasing demand for high power and high reliability. Railway auxiliary inverters are one component of railway electrical systems, providing power to auxiliary equipment such as lighting, air conditioning, and signalling. They are powered by a high-voltage (HV) continuous train line. The auxiliary converter transforms this high voltage into a voltage with parameters suitable for supplying all the electrical appliances of the wagon. Parallel interconnection of the outputs of the auxiliary converters installed on the individual wagons of the train via a common line can bring some advantages. . One of the main advantages is to increase the reliability and availability of such a system through active redundancy. Another advantage is the better configurability and flexibility, which allows reduction the number of train converters. In case of sufficient power dimensioning of converters, they do not have to be installed on every wagon [1]. These advantages include improved efficiency, higher power density, and better reliability.

Parallel operation of three-phase inverters is a complex problem, requiring careful consideration of the starting sequence, synchronization, and power sharing of the individual inverters. In this paper, we present the results of an experimental measurement of four parallel-connected three-phase inverters of railway auxiliary converters, with a focus on verifying the starting sequence and power sharing of the inverters.

2. Experimental Setup

The experimental setup consisted of four separate railway auxiliary converters, each consisting of an input HV converter, a 3-phase inverter module with a 3-phase sine filter, and an output contactor connecting the converter output to the common bus. The converters were powered by a common high voltage AC source, and the outputs were interconnected by cables with a length of 30 meters to form a common three-phase network. Two asynchronous motors were used as loads, a 15 kW motor powering the fan and a 137 kW motor. The circuit connection for parallel co-operation is shown in Figure 1, and the converter parameters are listed in Table 1.

Table 1. Parameters of the experimental setup

Nominal input voltage	1000 V / 16,7 Hz, 22 Hz, 50 Hz 1500 V / 50 Hz 1500 V DC 3000 V DC
Nominal output power	55 kVA
Nominal output voltage	3x400 V AC
Nominal output frequency	50 Hz
DC bus voltage	680 V DC
Switching frequency	8 kHz

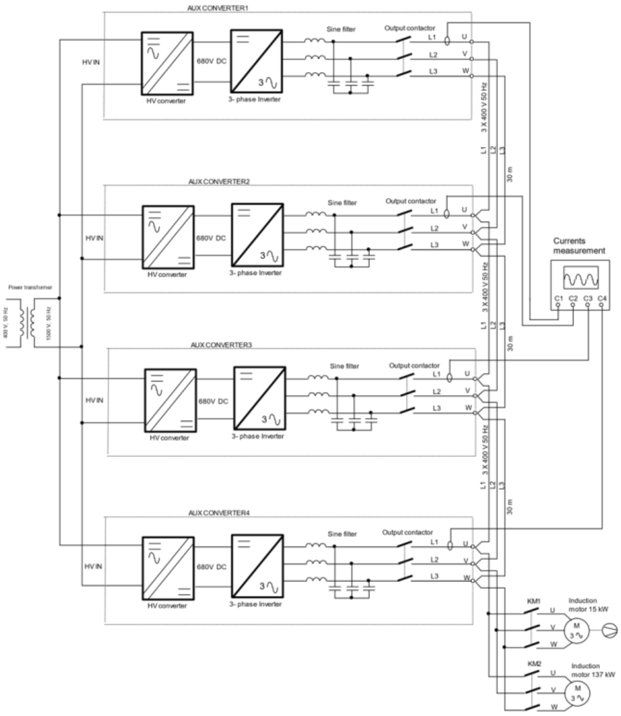
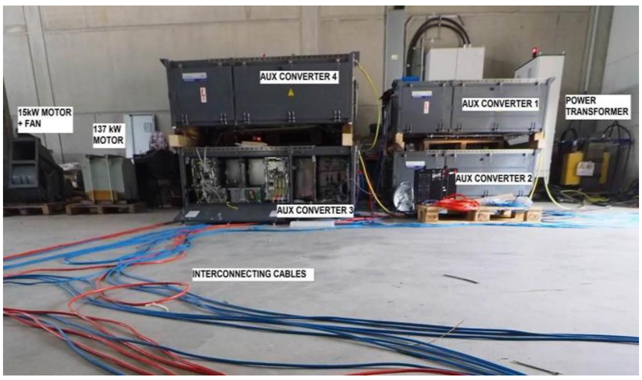


Figure 1. Hardware connection of the four parallel connected inverters to the input and output

The experimental setup is shown in Figure 2.



. **Figure 2.** Experimental setup of four parallel converter

3. Experimental measurements

The purpose of this measurement was to verify the ability of parallel co-operation of four three-phase inverters connected to common three phase bus, verifying the starting sequence of the inverters and power sharing by individual converters.

The converters are powered by 1500V 50Hz from a power transformer. After connection to the supply voltage, the input HV inverters begin to produce a 680V DC link voltage. In the inverters, the start sequence is activated and the random delay of the start of the inverter is generated by the software. One of the inverters is connected to the common bus as the first and the others are synchronized and sequentially connected to a common bus. Now all four inverters are connected in parallel and form a common three phase network. Measured line to line voltage waveform between U and V phases V_{U-V} of the common three phase grid is shown in Figure 3.

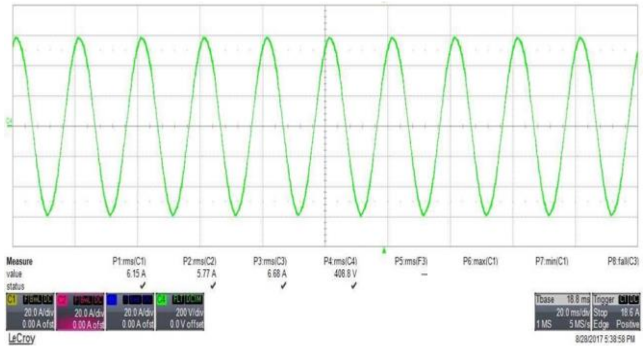


Figure 3. Line to line voltage V_{U-V} of the common three phase grid.

When a common network is formed, the load represented by 15 kW induction motor driving fan is added and the current sharing during motor acceleration and run is measured. Figure 4 shows the measured phase U currents of individual inverters (C1 – C4) and motor phase current (F3) during acceleration. The current waveforms during motor acceleration in detail are shown in Figure 5. The following RMS values of converter currents were measured during motor acceleration: Converter 1 phase U current I_{U1_RMS}=33.1 A, Converter 2 phase U current I_{U2_RMS}=35 A, Converter 3 phase U current I_{U3_RMS}=36.2 A, Converter 4 phase U current I_{U4_RMS}=36.9 A. The RMS value of the motor phase current was I_{M_RMS}=140.3 A.

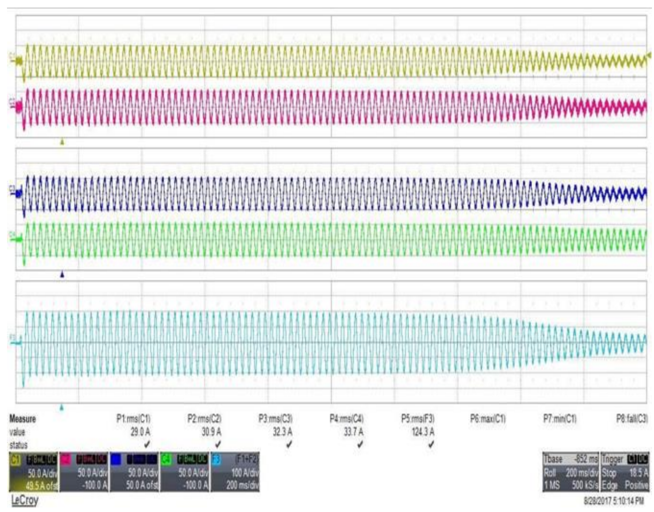


Figure 4. C1- converter 1 phase U current, C2- converter 2 phase U current, C3- converter 3 phase U current, C4- converter 4 phase U current, F3 – motor phase U current during 15 kW motor acceleration.

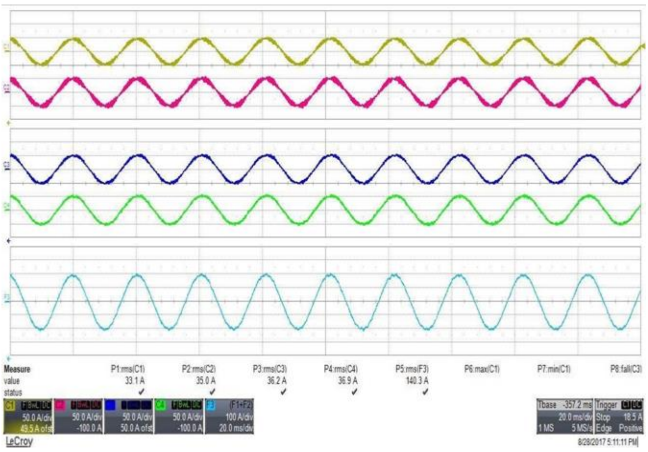


Figure 5. Detail of the current shown in Figure 4

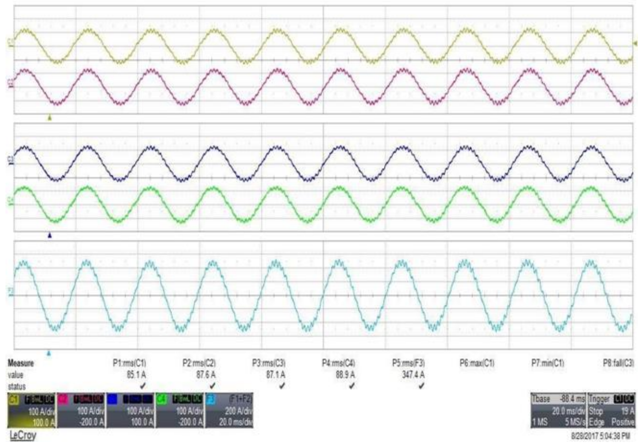


Figure 7. Detail of the current shown in Figure 6

Figure 6 shows converter currents and motor current during 137 kW no loaded motor acceleration. Motor is connected directly by the contactor to the common three phase bus created by four parallel connected converters. Currents in detail are shown in Figure 7. Measured converter currents were: Converter 1 phase U current I_{U1_RMS}=85.1 A, Converter 2 phase U current I_{U2_RMS}=87.6 A, Converter 3 phase U current I_{U3_RMS}=87.1 A, Converter 4 phase U current I_{U4_RMS}=88.9 A. The RMS value of the motor phase current was I_{M_RMS}=347.4 A.

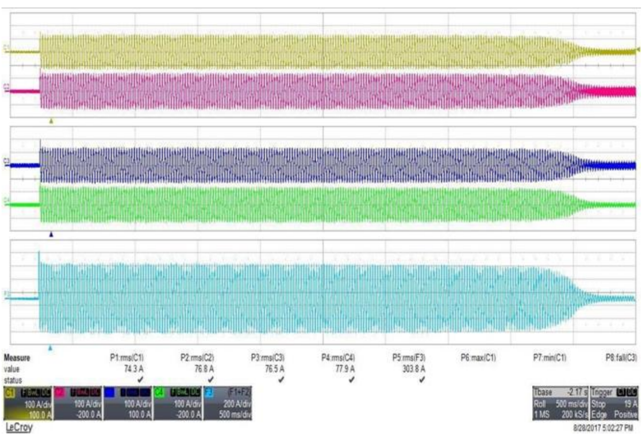


Figure 6. Currents during 137 kW motor acceleration. C1- converter 1 phase U current, C2- converter 2 phase U current, C3- converter 3 phase U current, C4- converter 4 phase U current, F3 – motor phase U current.

4. Conclusions

The purpose of this measurement was to verify the ability of parallel co-operation of four inverters installed in railway auxiliary converters. The converters were powered by 1500 V 50 Hz from transformer. After connection to the supply voltage, starting sequence of inverters was verified. All inverters were able to synchronize and connect to the common bus and stable operate in parallel connection. Furthermore, stable operation, dynamic response, and power sharing by inverters during 15 kW and 137 kW motor acceleration was tested. The constants of the control structure have been tuned to achieve good dynamic system responses, stability and good power sharing of the inverters under these conditions.

The ability to uniform power sharing can be seen from measured currents. The output currents of the inverters was divided in proportion Converter 1 – 23.6%, Converter 2 – 24.7%, Converter 3 – 25,6%, Converter 4 – 26.1% of the total load current during 15 kW motor acceleration. During 137 kW motor acceleration the current was divided in proportion: Converter 1 – 24.5%, Converter 2 – 25.1%, Converter 3 – 25%, Converter 4 – 25.4% of the total load current.

ACKNOWLEDGEMENTS

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High power – high frequency transformer design constrains

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Abstract This paper describes the design of a middle-frequency power transformer, its material composition and the design of the magnetic circuit and windings, operating in the frequency range 800 to 2000Hz, with a capacity of 200kVA, air-cooled, to be fed from a suitable frequency converter, characterized by reduced noise. The proposed solution allows the implementation of galvanically isolated DC-DC converters for auxiliary traction drives and other DC-DC converters.

Keywords power electronic system, electric machine, high power, high frequency

JEL Q4, L62, L69

1. Introduction

Power transformers can produce several types of noise, including magnetostriction noise, stray magnetic field noise, and electrical noise. The level of noise produced by a transformer depends on several factors, such as the design of the transformer, the quality of the materials used, and the operating conditions.

At a frequency of 1kHz, the noise level of a power transformer can vary widely depending on its size and design. In general, larger transformers tend to produce more noise than smaller ones due to their greater physical size and the larger magnetic fields they generate.

The noise level of a power transformer is typically expressed in decibels (dB) or in terms of sound pressure level (SPL) measured in decibels relative to a reference sound pressure level. The noise level of a typical power transformer ranges from around 20 dB SPL to 70 dB SPL, depending on the transformer's size, design, and operating conditions.

In summary, the noise level of a power transformer operating at a frequency of 1kHz can vary widely depending on its design and operating conditions. However, a typical range of noise level for such transformers is from around 20 dB SPL to 70 dB SPL.

EVPÚ a.s. has been developing and manufacturing static semiconductor traction converters for more than a decade, and part of the equipment of traction vehicles is also the need to design and develop smoothing chokes for traction motors or traction intermediate circuit. Several types of middle frequency power transformer and chokes been designed for traction converters.

2. Design of the high-frequency power transformer

Before the actual design of a power transformer, it is necessary to determine or establish the key parameters that this transformer should possess. These parameters are illustrated in Table 1. Based on these parameters, it is possible to mathematically calculate the required characteristics of the transformer, which can then be used to design and construct the power transformer.

Table 1. Input parameters for design of the high-frequency power transformer

Power [kW]	12
Input voltage [V]	452
Output voltage [V]	30
Conversion [-]	14
Magnetizing inductance [mH]	0.8
Primary series inductance [μH]	25
Secondary series inductance [nH]	127.5
Switching frequency [kHz]	125

An example design of a power transformer is shown in Figure 1. As can be seen in this figure, the transformer has multiple parallel windings made of high-frequency wires, which are terminated with ring eye terminals and connected in parallel on a PCB or power bus of the device.

The series resonant circuit for the transformer requires a resonant inductance and a resonant capacitance. The resonant inductance can be implemented as a separate inductor connected in series with the winding, or alternatively, the total leakage inductance of the transformer can be used as the resonant inductance.

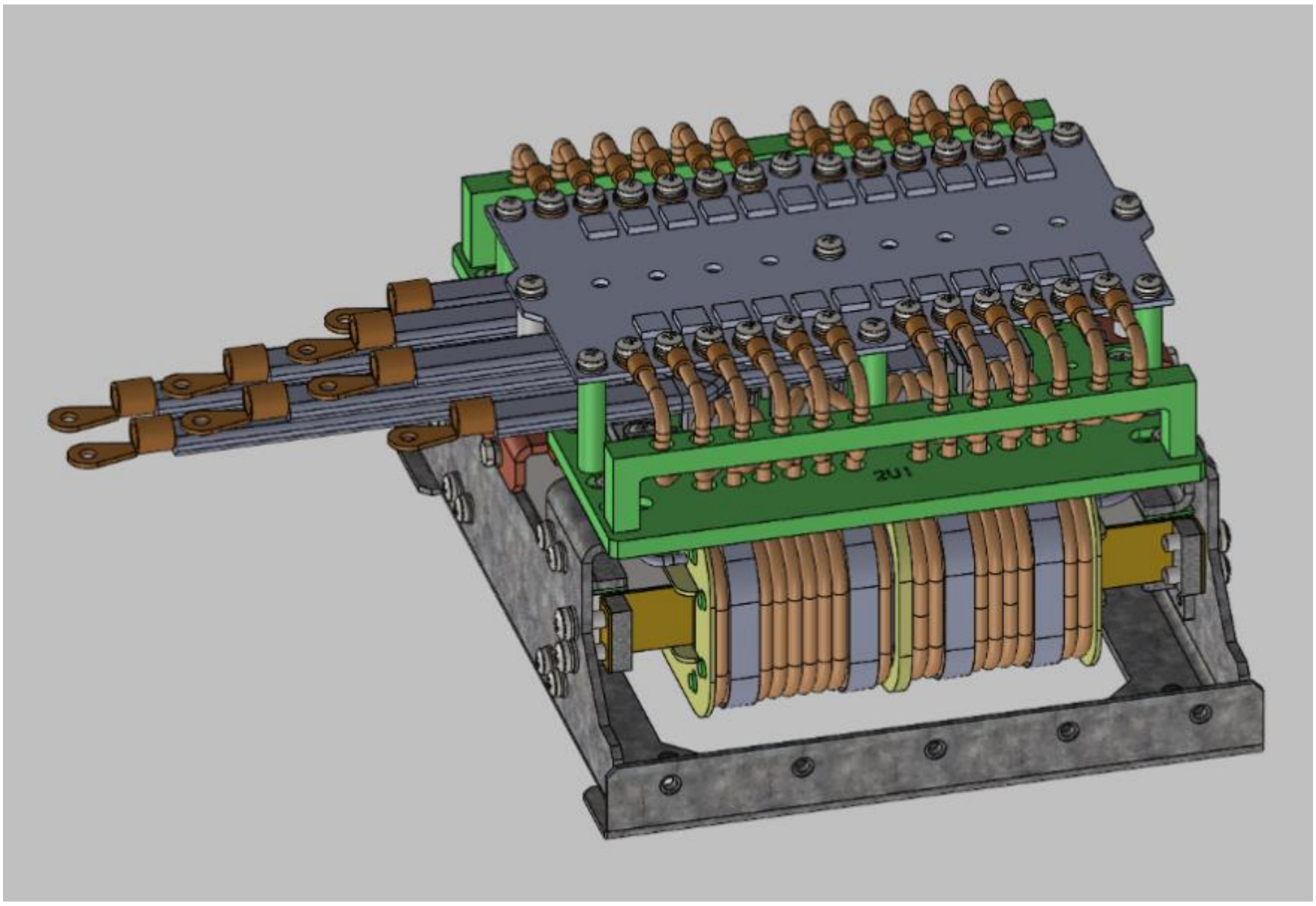

Figure 1. An example of the 3D design of power transformer with resonance capacitors board.

The selected type of inductance scenario has significant impact on the transformer design. Each method has its advantages and disadvantages. These are the two methods:

a) External inductor

- Requires an additional magnetic component.
- The desired inductance can be more precisely tuned during the inductor production.
- A transformer with tight coupling has low leakage inductance and lower losses.

b) Integrated inductance

- No need for an external inductor.
- Achieving the desired value may be challenging.
- Reproducibility may be poorer, and worse manufacturing tolerances can be expected.
- A deliberately poorly coupled transformer will have higher losses.

For this application the resonant capacitor will be created from multiple SMD capacitors connected in parallel. The series-connected resonant capacitors with the secondary winding will be located on the PCB above the transformer. The construction of the transformer includes the mounting of this board. If the actual resonant inductance deviates significantly from the planned value, it may be necessary to fine-tune the value of the resonant capacitance or adjust the switching frequency of the charger.

During the process of the design of the transformer with given parameters and specification, several approaches were considered. The approaches were to optimize the dimension parameters with the inductor with high inductance but lower operating current on the primary side or the inductor with low value of the inductance but with operating current at value of 400 A. For both different solutions of the main magnetic circuit, designs were created, processed, and evaluated. However, the approach was taken to use a transformer topology with defined leakage inductance. Construction documentation was prepared for this topology, based on which a prototype was manufactured. This prototype design was named T1N-12-452/30. The 3D design of this prototype design can be seen in Figure 1.

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3. Measurements of the designed transformer

The measurements of the designed transformer were conducted on a laboratory-created prototype, the T1N-12-452/30, whose results were compared with a professionally constructed transformer from the German company STS Trafo. STS Trafo is actively involved in this field and was approached with a request to construct this transformer design. They received the same assignment and focused on designing solutions for a "good" transformer and an additional inductor with defined inductance, both of which are integrated into a single module. STS Trafo's transformer can be seen in Figure 5 and prototype of the Chopra inductor is shown in Figure 6.

3.1. Experimental measurements of the laboratory-created prototype transformer

Experimental measurements on the prototype transformer were conducted with the aim of adjusting the leakage reactance of the transformer by changing the windings position.

The measured data of the laboratory-created transformer prototype is graphically represented in Figures 2, 3, and 4. Figure 2 shows the open-circuit characteristic of the transformer at switching frequency of 120 kHz. The short-circuit characteristic of the transformer prototype obtained at a switching frequency of 30 kHz is shown in Figure 4. The magnetizing inductance of the transformer (Lm = *f*(U)) at a switching frequency of 120 kHz is presented in Figure 3.

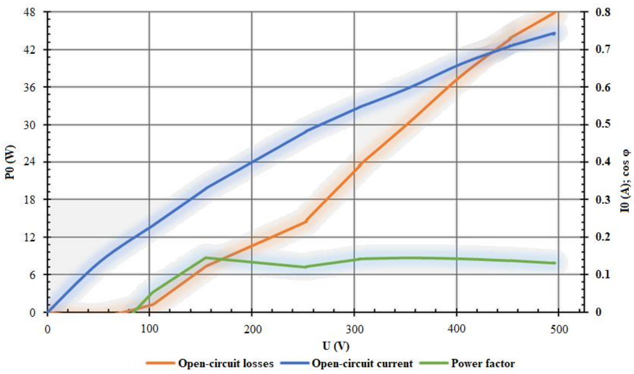

Figure 2. Open-circuit characteristic of the lab-created transformer.

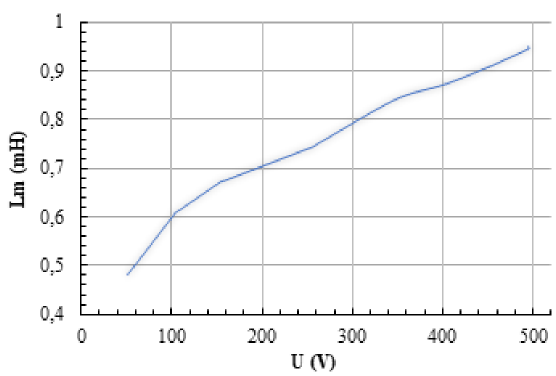

Figure 3. Magnetizing inductance of the lab-created transformer.

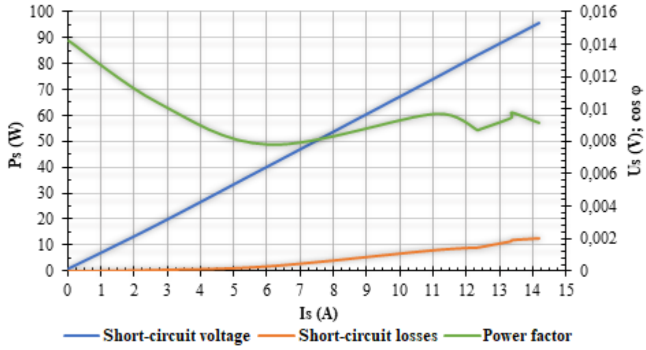

Figure 4. Short-circuit characteristic of the lab-created transformer.

Through measurements on the designed laboratory-created transformer, it was found out that the limiting value of the leakage inductance is 38 µH. Further increasing the gap between the windings of the transformer resulted in a stable value, indicating that further increases of the gap does not increase the value of leakage inductance.

3.2. Experimental measurements of the STS Trafo's prototype transformer

Since the company STS Trafo got the same specification for their prototype of the same named transformer, the measured output parameters should be very similar. The STS Trafo prototype with Chopra inductor configuration is shown in Figure 5 and 6.

Figure 5. Designed transformer prototype constructed by STS Trafo.

Figure 6. Prototype of the external Chopra inductor by STS Trafo.

Just like in the case of the laboratory-created prototype transformer, the open-circuit and short-circuit characteristics of this transformer were also measured. They are depicted in Figure 7 (open-circuit characteristic) and Figure 8 (short-circuit characteristic).

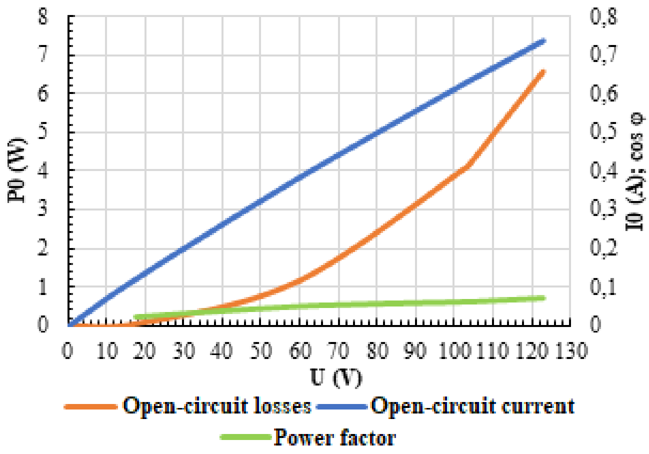

Figure 7. Open-circuit characteristic of the STS Trafo transformer.

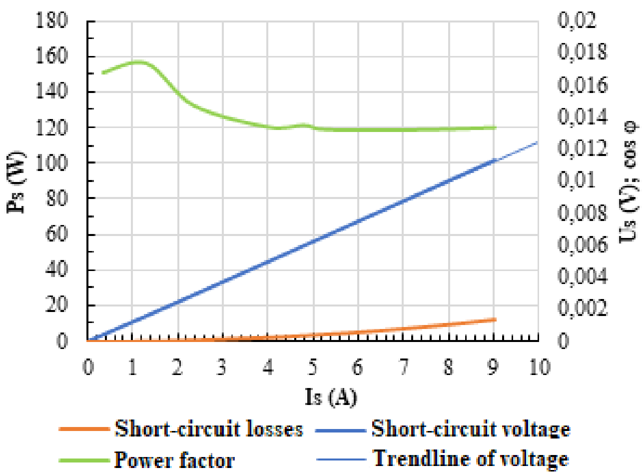

Figure 8. Short-circuit characteristic of the STS Trafo transformer.

Both measured characteristics on the prototype assembled by STS Trafo were obtained at a switching frequency of 30 kHz. The measured value of the limit leakage inductance for this prototype is 58 μH.

4. Conclusions

This paper investigates the noise level of power transformers operating at 900Hz, the source of which is the transformer core. The study examines the factors that influence the noise produced by the core of a power transformer, and consequently the selection of a suitable core type and manufacturing technology. The design of a middle-frequency power transformer, its material composition and the design of the magnetic circuit and winding, operating in the frequency 900Hz, with a power 200kVA, cooled by air, to be fed from a suitable frequency converter characterised by reduced noise, are described. The proposed solution allows the implementation of galvanically isolated DC-DC converters for auxiliary traction drives and other DC-DC converters. The findings of this paper can be used in the design and operation of power transformers and help mitigate the impact of transformer noise on the surrounding environment.

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Input impedance of static power inverter of auxiliary drives of rolling stock according to UIC 550-3

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Abstract This paper focuses on the topic of the input impedance of static power inverters, which is a crucial parameter for controlling and regulating power inverters in rolling stock. The standard UIC 550-3 specifies the requirements for the input impedance of static power inverters used as auxiliary drives on rolling stock.

Keywords input impedance, UIC 550-3, power inverter

JEL L63, L69

1. Introduction

This paper deals about the input impedance of static power inverter is a critical parameter for control and regulation of power inverters in rolling stock. UIC 550-3 is the standard that specifies the input impedance requirements for static power inverters that are used as auxiliary drives on rolling stock. This document specifies that the input impedance of a static power inverter must meet certain criteria to ensure reliable operation and minimise power losses. In this article, we will discuss the importance of input impedance for static power inverters used as auxiliary drives for rolling stock according to UIC 550-3 and its impact on overall system efficiency.

2. Input impedance of the inverter

The input impedance of an inverter is given by the ratio of the input voltage of a given frequency that is injected to the DC signal to the current of a given frequency that the inverter draws. Zi(f) = Ui(f) / Ii(f) when the inverter is supplied with DC power. The UIC 550-3 standard prescribes the minimum impedance of an inverter for a particular frequency. Figure 1. shows a plot of the dependence of the required minimum input impedance (ZI) for a particular frequency. The graph shows that, for example, for a frequency of 50 Hz, the minimum required frequency is 80 Ω , Figure 1.

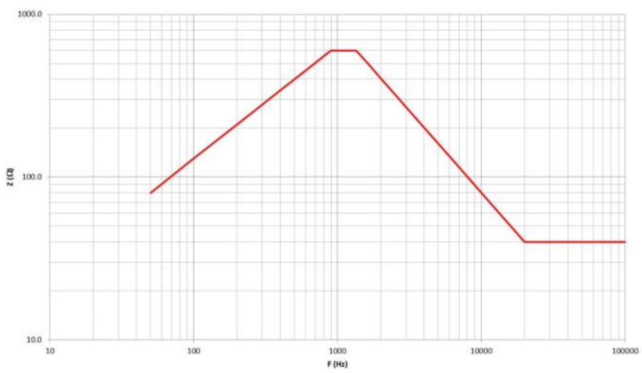

Figure 1. Dependence of the minimum required impedance of the converter for a particular frequency.

2.1. Inverter input impedance measurement technique

The input impedance (ZI) value was measured using the circuit shown in Figure 2. The input impedance was measured on a JN3029/400 high voltage inverter, which was configured as a JN3028 inverter. In the JN3029 inverter, the charger was disconnected from the intermediate circuit and the inverter was configured the same as in the JN3028 inverter. The auxiliary inverter was connected to the high voltage source A1. The injected voltage of the de-sired frequency was generated by the SN31-680/400 inverter. The total input current of the inverter, was measured using a current transducer. The AC component of the input current was measured using a Rogowski coil type Rocoil. The coil was connected to a Rocoil type integrator. The input voltage of the converter was measured using a high voltage probe. All measured voltages and currents were evaluated using the SIRIUS measurement system. The data from the SIRIUS measurement system was evaluated by the DAWEsoftX software running on a Lenovo laptop. The HV inverter was loaded with a three-phase inverter only. The inverter fed an asynchronous three-phase motor. The motor was connected

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to a dynamometer, which was used to load the motor with a constant torque of 100 Nm.

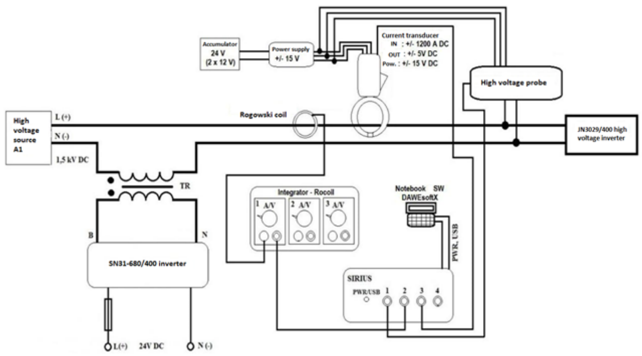

Figure 2. Block diagram of input impedance measurement of auxiliary converter JN3029.

The first step was to measure the impedance of the inverter without any intervention in the inverter hardware or software. The aim of the measurement was to find out what values of input impedance (ZI) the inverter achieves without modification of the control software. Figure 3. shows a plot of the dependence of the input impedance (ZI) on the frequency of the injected signal, where the limiting impedance values for each frequency are marked in red, the maximum measured values are marked in blue, and the minimum measured values are marked in brown.

From Figure 3. it can be seen that the input impedance of the converter is below the required limit in almost the entire frequency band of 40 Hz - 10 kHz. The impedance is above the limit only for injected frequencies above 3500 Hz, see Figure 3. The task of modifying the control program was to adjust the control of the high voltage (HV) converter so that the value of the input impedance (ZI) is always above the desired limit. The control method, including the necessary hardware modifications, is described in the following chapter.

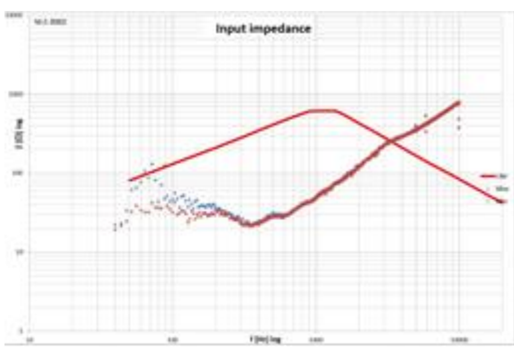

Figure 3. Dependence of input impedance on frequency of injected signal.

2.2. Inverter control method to increase the input impedance of the inverter

The standard control of a high voltage (HV) inverter consists of two main control members. The first is the D_shift controller, which determines the action of a given control member based on the voltage in the first intermediate circuit (Udc_ref1) and the input voltage Ui_shift. The second control member is a pair of PI controllers connected in series. The first PI controller determines the reference value of the input current based on the actual and the desired value of the second intermediate circuit. The second PI controller, based on the given reference and actual input current, calculates an action for the given control member. The action hits from the two members are summed and the result is fed to the PWM modulation input. The resulting pulses from the PWM block directly drive the individual IGBT control transistors of the inverter. A schematic of the inverter control, without input impedance (ZI) compensation, is shown in Figure 4.

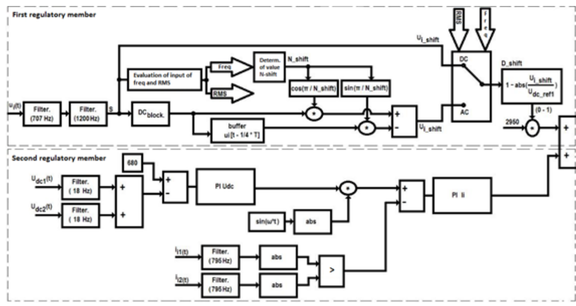

Figure 4. Schematic of inverter control without input impedance compensation.

The modification of the control of the HV converter consisted of modification of the control software and hardware modification of the analogue input board. It was necessary to replace the filter capacitor on the analog input board, on the AI0 input. The originally fitted capacitor with a capacitance of 4.4 μF was replaced with a capacitor with a capacitance of 470 nF. The reason for the replacement was the need to evaluate the injected signal up to a frequency of 5000 Hz. The originally fitted capacitor caused a high attenuation of the amplitude of the injected signal already at a frequency of about 850 Hz. The modification of the control software consisted of two main steps. The first step was the modification of the Ui_shift signal generation. The AC (injected) component of the DC signal undergoes the signal adjustment. It was first necessary to extract the AC (injected) portion of the input voltage from the signal, thus obtaining a signal that contains only the AC (injected) component of the input voltage. The frequency and the effective value are then determined from the signal. Based on the data obtained, the amplitude of the signal is changed and the signal is shifted along the time axis. The effective value of the input voltage is added to the signal thus modified.

The resulting signal is then the Ui_shift signal, which is applied to the D_shift input of the controller. See. Figure 5. Block diagram of the inverter control in the case of active input impedance (ZI) increase. The second step is to add a controller for the AC component of the input current. In this case, it is a PI controller that modifies the control so that the AC component of the input current is zero. Similar to the signal conditioning for the D_shift controller, the AC component of the input current must first be obtained. The given signal is then applied to the input of the PI controller where the desired value for the given signal is zero. Unlike the D_shift controller, which operates over the entire frequency range of the input injected signal (40 - 5000 Hz), the given PI controller operates only when the frequency of the injected signal is less than 700 Hz. Figure 5. shows a block diagram of the inverter control in the case of active input impedance (ZI) increase. The above modifications represent a third control term, which is active only in the case of a DC voltage at the inverter input and only if the program detects an injected voltage at the inverter input. Figure 6. shows a schematic of the control with the above third control element, which is divided into two parts.

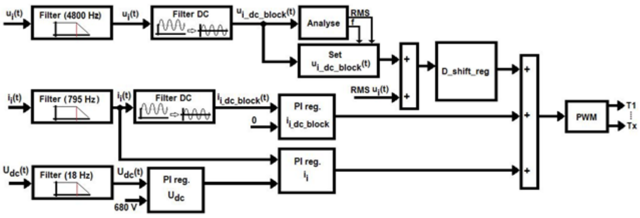

Figure 5. Block diagram of inverter control in case of active input impedance increase.

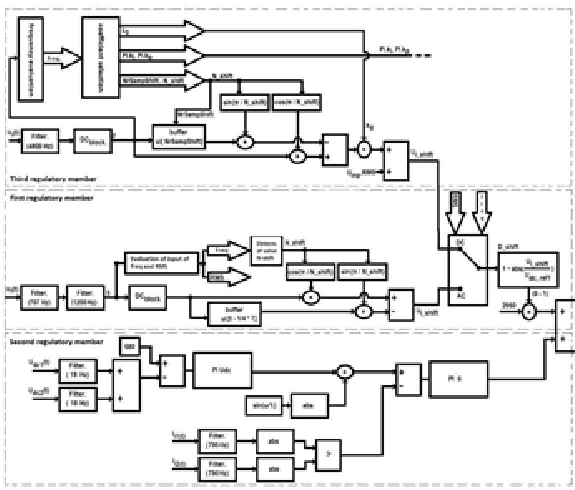

Figure 6. Schematic of inverter control in case of active input impedance increase.

As shown in Figure 6 the control program of the HV converter varies the parameters k0 - gain of the injected signal, kp - PI controller parameters of the zero ac component of the input current (ki = 0.015 for all frequencies of the injected signal), N_shift - the shift parameter of the injected signal along the time axis, and NrSampleShift, according to the frequency of the injected signal where : NrSampleShift = ¼ of the period of the injected signal converted to the number of samples. The correct values of the above parameters were obtained experimentally for each frequency. The obtained results, including the minimum and maximum impedance values for each frequency will be presented in the next section.

2.3. Measurement Results

Experimental results k0 - gain of injected signal, kp - parameters of PI controller of zero alternating component of input current, N_shift - parameter of shift of injected signal along the time axis proceeded as follows. The diagnostic program of the HV inverter allowed to change individual parameters. The input impedance was measured according to the circuit shown in Figure 2 and the value was available immediately when the parameters were changed. By the given procedure it was possible to detect immediately the influence of the change of individual parameters on the input impedance. During the experiments, the value of only one of the parameters was changed each time and the effect of the coefficient on the input impedance (ZI) value was evaluated based on the input impedance (ZI) measurement. The experiment was terminated when the input impedance (ZI) was reduced by changing the parameter. A summary of the results of the above parameters for each frequency is given in Table 1. Table 1 also shows the results of the minimum and maximum impedance.

Table 1. Summary of results of individual parameters for each frequency.

U_{inject} [Hz]	k_0 []	N_shift []	Kp []	ZI min [Ω]	ZI max [Ω]	Limit ZI [Ω]
50	1,05	1,667	85	127	132	80
75	1,05	1,667	85	203	215	106,1
100	1,328	1,667	84,9	386	429	129,7
200	1,250	1,148	75,0	1416	4547	210,3
300	1,250	0,179	75,0	1287	12737	279
400	1,250	0,140	75	779	1874	340,9
500	1,119	0,125	74,9	903	2302	398,3
600	1,15	0,120	1,0	940	4049	452,3
700	1,149	0,119	1,0	652	3671	503,6
800	1,099	0,115	1,0	690	1964	552,7
900	1,019	0,115	1,0	2877	32994	600
1000	1,0	0,115	1,0	1350	3796	600
1100	0,998	0,121	1,0	1402	2730	600
1200	0,850	0,110	1,0	3339	4957	600
1300	0,851	0,1160	1,0	1285	1650	600
1400	0,722	0,1079	1,0	1513	2116	578,5
1500	0,709	0,1141	1,0	591	3193	539,7
1600	0,580	0,115	1,0	3565	3698	505,9
1700	0,500	0,107	1,0	3740	5538	476
1900	0,307	0,113	1,0	3162	5520	425,6
2100	0,167	0,0939	1,0	9233	98123	384,9
2300	0,05	0,0682	1,0	3663	5225	351,3
2600	0,197	0,04900	1,0	5045	22387	310,6
3100	0,897	0,0483	1,0	623	1002	260,3
4000	4,55	0,0565	1,0	246	312	201,5

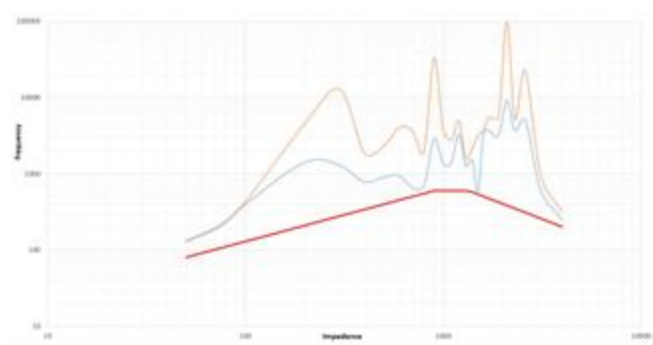

Figure 7. Dependence of the minimum and maximum input impedance on the frequency of the injected signal.

Figure 7 shows a summary of the results achieved. The red waveform represents the limiting values of the input impedance for each frequency. The blue waveform represents a summary of the minimum input impedance values that were measured in the experiments with the set parameters for each frequency. The brown waveform represents the sum of the maximum input impedance values that were measured in the experiments with the set parameters for each frequency. From Figure 7, it can be seen that the achieved input impedance values, for the individual frequencies, are above the required limits for the individual frequencies. The highest input impedance was measured when the frequency of the injected signal was 2100 Hz whereas the closest to the allowed limit was the input impedance when the frequency of the injected signal was 4000 Hz (44.5 Ω above the limit).

All experiments were performed at one input voltage level, approx. 1550 V and one loaded HV inverter, the inverter input current Ii approx. 13A. For the injected signal frequencies of 50 Hz, 75 Hz,100 Hz, 200 Hz and 3100 Hz, the effect of load variation on the input impedance was also experimentally measured so that the input impedance was measured with the same parameter set at three different loads. The results of the given measurements are shown in Table 2, 3, 4, 5 and 6. Where Ii is the effective value of the input current and the note shows the value of the motor load that was connected to the inverter.

Table 2. Measurement of the effect of load variation on the input impedance of the inverter for Uinject = 50 Hz.

k_0 []	N_shift []	k_p []	ZI min [?]	ZI max [?]	I_i [A]	Poznámka
1,05	1,667	85	126	132	10,3	50 Nm
1,05	1,667	85	127	132	14,0	100 Nm
1,05	1,667	85	118	124	19,6	150 Nm

Table 3. Measurement of the effect of load variation on the input impedance of the converter for Uinject = 75 Hz 3. Page Style

k_0 []	N_shift []	k_p []	ZI min [Ω]	ZI max [Ω]	I_i [A]	Poznámka
1,050	1,6668	85	220	231	8,9	50 Nm
1,050	1,667	85	203	215	13,8	100 Nm
1,05	1,6674	85	180	190	19,7	150 Nm

Table 4. Measurement of the effect of load variation on the input impedance of the converter for Uinject = 100 Hz.

k_0 []	N_shift []	k_p []	ZI min [Ω]	ZI max [Ω]	I_i [A]	Poznámka
1,328	1,6674	84,9	298	322	8,5	50 Nm
1,328	1,6675	84,9	396	429	13,5	100 Nm
1,328	1,6672	84,9	371	417	19,3	150 Nm

Table 5. Measurement of the effect of load variation on the input impedance of the converter for Uinject = 200 Hz.

k_0 []	N_shift []	k_p []	ZI min [Ω]	ZI max [Ω]	I_i [A]	Poznámka
1,250	1,1486	74,9	561	805	8,9	50 Nm
1,249	1,1500	74,9	982	1654	12,5	100 Nm
1,2490	1,1489	74,9	795	1559	19,0	150 Nm

Table 6. Measurement of the effect of load variation on the input impedance of the converter for Uinject = 3100 Hz

k_0 []	N_shift []	k_p []	ZI min [Ω]	ZI max [Ω]	I_i [A]	Poznámka
0,9	0,04820	1,0	274	327	8,5	50 Nm
0,9	0,04820	1,0	623	1002	13,5	100 Nm
0,9	0,04820	1,0	575	781	19,3	150 Nm

The effect of load variation on the input impedance for the other frequencies has not been investigated. The load for the remaining frequencies was about 13 A of input current. The motor connected to the inverter was always loaded with a torque of 100 Nm. Also, the impedance was not measured if the injected signal had a frequency outside the value given in Table 1. The given experiments were not performed due to their high time requirement. Example: Frequencies in the range 50-4000 Hz in steps of 5 Hz at 5 load levels will give a total of 3950 experimental measurements. Which with a time requirement of approx. 1 hour per measurement is 3950 hours = approx. 526 working days = approx. 24 months of work on experimental measurements alone.

3. Conclusions

As presented in the previous chapter, by actively controlling the input impedance, it was possible to increase the input impedance of the HV converter above the required limit. All the experiments of changing the coefficients, as described in the previous chapter, were performed only for the frequencies listed in Table 1. If the frequency of the injected signal is between the values in Table 1, the values for that frequency are calculated by selecting the next higher value and the next lower value from Table 1 and fitting a straight line through the given parameters. In other words, the next higher value and the next lower value are used for the linear substitution. The given procedure is used to determine the coefficients "a" and "b" of the formula "y = a*x+b", where "x" is the input frequency of the injected signal and "y" is the value of the parameter we need to determine. The control program of the HV inverter has been modified according to the results and is archived as version R000067_02 for the needs of the JN3028.x inverter.

ACKNOWLEDGEMENTS

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Measurement of the influence of changes in the HV converter SW on the input impedance

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Abstract This paper, we focus on the measurement of the effect of the SW filter division frequency shift of the measured input voltage on the value of the input impedance at an input signal frequency of 50 Hz. The aim of the measurement is to find out what effect this shift has on the input impedance and thus on the performance and efficiency of the whole system.

Keywords impedance matching, measurement, high voltage

JEL L63

1. Introduction

A SW HV inverter (Switched Voltage Network Inverter) is an electronic device that is used to change one voltage system to another. It is a device that can change the voltage and current in different circuits. Nowadays, it is increasingly used as a means of regulating voltage and current in the event that, for example, it is necessary to adjust the voltage and current from the production of solar panels for homes or businesses.

The SW HV converter allows the conversion of one voltage system to another by means of different switches. These switches open and close the circuits so that the voltage and current can be regulated. Thus, a SW HV converter is a device that can change the voltage and current in different circuits. Nowadays, SW HV inverter is used in various applications such as voltage and current regulation in the case of solar panels for homes or businesses. It is also used in voltage and current regulation in electric vehicles or voltage and current regulation in various industrial applications. SW HV converter consists of various components such as transistors, diodes, capacitors and transformers.

These components are used to form various circuits and to regulate voltage and current. For example, capacitors are used to maintain a constant voltage, diodes are used to protect the circuit from return current, and transistors are used to open and close the circuit.

2. The effect of the converter on the input impedance

The goal of the described experimental measurements was to verify the influence of changes in the control SW of the HV inverter CZE on the input impedance. The measurements were carried out on the ST-JN-3-1 bench at input voltage U_{in}=1500 V DC and load power P=26 kW.

2.1. Effect of changing the SW filter frequency of the measured input voltage

The measured value of the input voltage U_{in} passes through a low-pass filter in the control software and then enters the D_{shift} calculation block, whose output directly affects the reference value entering the PWM modulator. The input impedance was measured for filter frequencies of 80 Hz, 250 Hz, 500 Hz and 1000 Hz. The measured values are shown graphically in Figure 1.

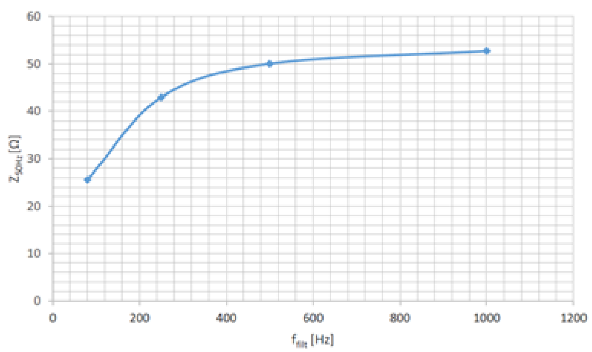

Figure 1. Measured waveform of input impedance vs. SW filter frequency for 50 Hz input signal.

In the measurement, it was found that the shift of the division frequency has a significant effect on the value of the input impedance. Specifically, as the filter frequency increased, the input impedance decreased. This can have a negative effect on the reliability and efficiency of the overall system.

The effect of the division frequency shift on the input impedance is important in terms of control and regulation of power converters. In the case of using a static power converter as an auxiliary drive of a rolling stock, it is critical that the input impedance meets the specified criteria according to UIC 550-3. This standard specifies that the input impedance of a static power converter must meet certain criteria to ensure reliable operation and minimise power losses.

Currently, active input impedance control attempts to raise the input impedance above the required limit. Experiments are aimed at changing the coefficients for different frequencies, with the calculated values used for linear compensation. The control program of the power converter is then modified according to the experimental results.

Overall, the effect of the SW filter cut-off frequency shift on the input impedance is an important topic in terms of power converter control and regulation. Finding out the optimal filter frequency can improve the reliability and efficiency of the whole system, which has a positive impact on the operation.

Next, the dependence of the input impedance of the converter on the frequency of the injected signal was measured using control software with the input voltage filter frequency adjusted to 1000Hz. The measured values are for comparison to the graph from the previous measurements with the unadjusted filter (Fig. 2).

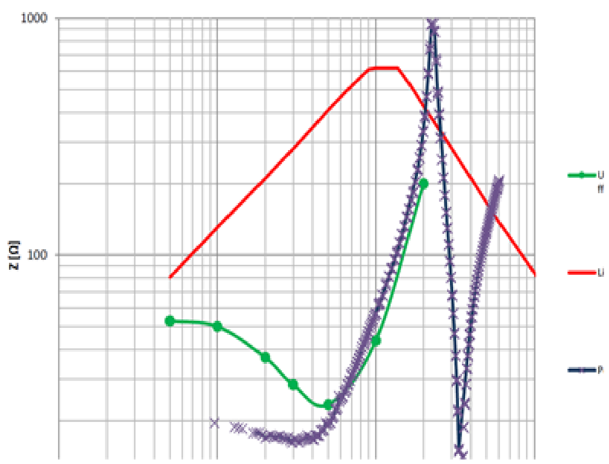

Figure 2. Measured input impedance waveforms with the modified SW filter value and with the original SW

2.2 Input impedance measurement with added ripple compensator of current to SW HV converter

In this measurement, the effect of adding a ripple current compensator to the control SW of the HV converter on the value of the input impedance was investigated. The AC component is separated from the measured input voltage, which is multiplied by a factor (gain) A and directly affects the reference value entering the PWM modulator of the HV converter.

This compensates for the effect of the input voltage ripple on the input current ripple of the converter, which should lead to an increase in input impedance. The dependence of the input impedance on the gain value A of the compensation term was measured for the values of input signal frequencies of 50 Hz, 100 Hz, 200 Hz and the SW filter input voltage frequency of 1 kHz and 1,5 kHz.

The measured input impedance waveforms are shown graphically in Fig. 3.

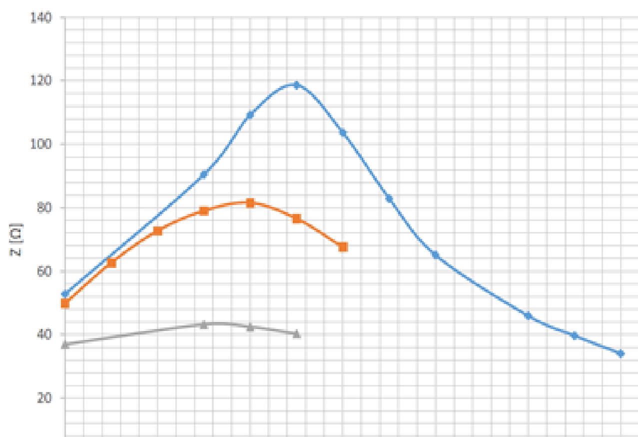

Figure 3. Input impedance waveforms as a function of compensator gain

Furthermore, the dependence of the input impedance on the frequency of the injected signal was measured with the addition of A=0.5 compensation element with constant gain A=0.5 to the control SW of the HV converter. The measured waveform of the impedance is shown in the graph in Fig. 4.

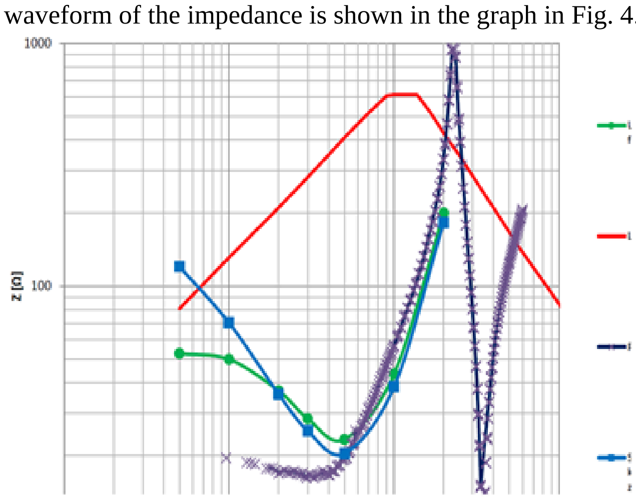

Figure 4. Measured input impedance waveforms with adjusted SW filter value, with added current ripple compensator and with the original SW

3. Conclusions

In this paper, we address the issue of the input impedance of a static HV converter, which is a critical parameter for the control and regulation of converters in a powertrain. According to the UIC 550-3 standard, the input impedance of a static HV inverter used as an auxiliary drive in powertrain vehicles must meet certain criteria to ensure reliable operation and minimize power loss. In this work, we try to find out how and what modifications to the dilution software can help to increase the input impedance. The first step was to investigate the effect of the SW filter divider frequency shift of the measured input voltage on the value of the input impedance at an injected signal frequency of 50 Hz. The measured value of the input voltage U_{in} is low-pass filtered in the controlling SW and then enters the D_{shift} calculation block, whose output directly affects the reference value entering the PWM modulator. The input impedance was measured for different filter frequencies, namely 80 Hz, 250 Hz, 500 Hz and 1000 Hz.

From the measurements, it was found that shifting the filter cut-off frequency to higher values results in an increase in the input impedance, especially at lower frequencies of the injected signal.

At frequencies above 500 Hz this effect is negligible. In the next step, we added a current ripple compensation block to the dilution SW of the HV converter and investigated the effect of this compensator on the input impedance increase.

From the waveforms, we saw that the maximum impedance was obtained for a certain optimum gain value of the A_{opt} compensation element, while this value varies for different frequencies. As the frequency increases, the value of optimum gain decreases. From the input impedance waveform, we saw that further increase in input impedance was achieved at lower values of the frequency of the injected signal. For a frequency of 50 Hz, the input impedance value was achieved.

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Measurement Of Parallel Operation Of Inverters To Common 3 Phase Network

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Abstract In the article, we describe the measurement of parallel cooperation of inverters connected to a common three-phase network on train carriage with real loads. In the beginning, we will describe the used equipment and then we will describe the individual measurement procedures and their results. We will show the results of the measurements, when loading two inverters with two train carriage, four and eight carriage. Finally, the results of measurements with 6 inverters power on and a load of up to 14 train carriages.

Keywords measurement, inverter, 3 phase network, train carriage

JEL L62, L69

1. Introduction

Testing the parallel cooperation of converters on six wagons, which were continuously connected and thus created one common three-phase network, from which 14 compressors were powered. The aim of the testing was to test the latest software for inverters with vector control, intended primarily for the operation of several inverters in a common three-phase network. The converters were powered from high voltage and the power supply range 1.5kV AC 50Hz was used. Two types of refrigerated containers were used on the wagons: ThermoKing and Carier. The starting current of the ThermoKing compressors was higher (the instantaneous value was up to 200A, i.e. 100A higher than in the case of the Carier cooling unit). The reason for the more difficult start is the fact that the Thermoking does not have a bypass valve and during the start its compressors run into back pressure. Even the steady consumption of Thermoking cooling units (20-22A) was slightly higher than in the case of Carier (18-20A).

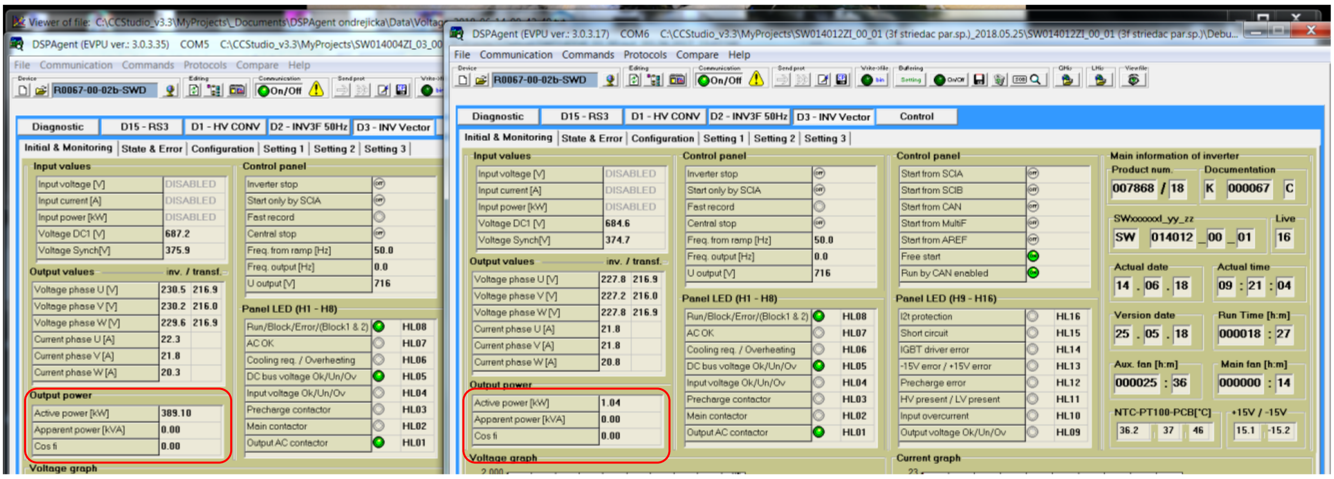
7 cars were connected to HV, but the three-phase outputs were not interconnected at first. We gradually connected them to the common network. During the test, the inverters were set to a nominal voltage of 3x380V. We have gradually verified the current operation with different number of converters (up to the number of max. 6 active converters) and different number of containers (up to the number of max. 14 containers).

2. Measurement of current for carriage load

First, we connected the first two inverters and tested parallel cooperation only with them using two refrigerated containers. Each container consumed approximately 20A when powered by 3x380V. In figure 1 below, it can be seen that the converters divided the consumption of 40A equally, about 20A each (the values of the phase currents in the picture also include the consumption of the internal sine filters). The output voltage under load dropped by 5V, i.e. to 375V.

2.1 A load of four containers

At the beginning, we let the load with two containers run for 5 minutes. The voltage was stable, and the currents did not fluctuate. After five minutes, we turned on the other two connected containers. The total consumption of 80A was divided between two inverters of approx. 40A each. The output voltage reached 3x370V at half the nominal load. Results of measurement is shown in figure 2.



Current phase U [A]	22.3
Current phase V [A]	21.8
Current phase W [A]	20.3

Current phase U [A]	21.8
Current phase V [A]	21.8
Current phase W [A]	20.8

Figure1. Connection of two inverters and two refrigerated containers

Current phase U [A]	39.5
Current phase V [A]	39.9
Current phase W [A]	38.5

Figure 2. Connection of two inverters and four refrigerated containers

During five minutes, the voltage and current did not fluctuate, the power was distributed evenly the whole time. Then we turned off one of the two running inverters to see if the other inverter's output would oscillate, but there was no problem. All four containers were fed from one inverter and drew approximately the nominal load. The combined voltage at the output of the running inverter under this load dropped to 3x355V, which means a 25V drop from the nominal value (less than 7% drop).

Current phase U [A]	78.7
Current phase V [A]	75.5
Current phase W [A]	74.5

Figure 3. One inverter in operation with the connection of four containers

In figure 4 shows how the output voltage (red color) and output current (blue color) fluctuated during this transition event. After about 2.5 seconds, the output voltage was stabilized. The horizontal axis represents the time axis in seconds

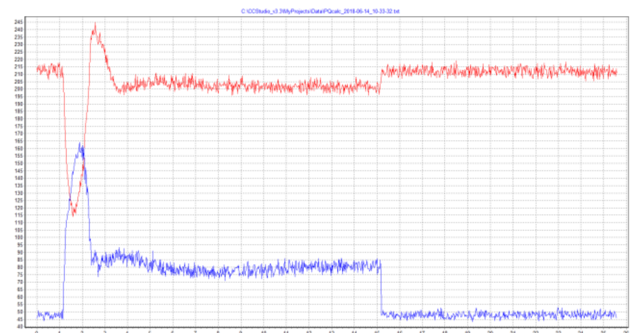


Figure 4. Output of the first inverter after switching off the second inverter when loaded with four containers

After restarting the switched-off inverter, the inverters again divided the power equally and both consumed 40A each. Not one of the cooling containers fell out during the transition. In this case, stabilization took less than 1.5 seconds, as we can see in figure 5.

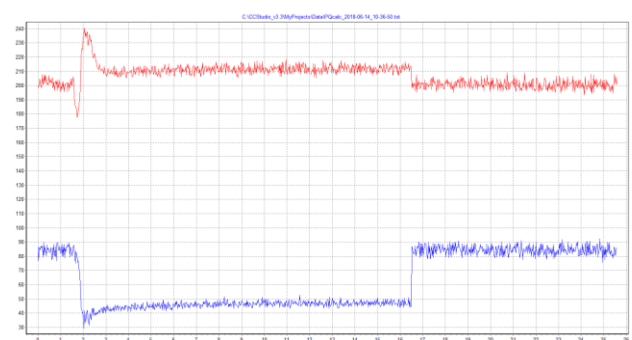


Figure 5. Output of the first inverter after the second inverter is switched on again when loaded with four containers

2.2 A load of eight containers

We left the first pair of converters blocked and put another pair into operation. All four wagons were connected to a common three-phase network so that we could use the full load (8 containers), which should represent the nominal load for two converters. Four containers were released and we released other containers gradually. First, we released the fifth container (Figure 6).

Current phase U [A]	52.4
Current phase V [A]	52.7
Current phase W [A]	51.0

Figure 6. Connection of two inverters and five refrigerated containers

After 20 seconds, we started two more compressors at the same time (Figure 7).

Current phase U [A]	70.3
Current phase V [A]	72.3
Current phase W [A]	69.1

Figure 7. Connection of two inverters and seven refrigerated containers

Both inverters worked the same, there were no voltage fluctuations even with a larger load that was added in steps, because in this case two compressors (sixth and seventh) were started at the same time. Each of the compressors had a capacity of up to 150A rms. After a minute, we released the last eighth container (Figure 8).

Current phase U [A]	78.7
Current phase V [A]	76.0
Current phase W [A]	77.7

Figure 8. Connection of two inverters and eight refrigerated containers

Even in this case, the combined voltage under this load dropped to 3x355V, which means it dropped by 25V (just like when only one inverter and four containers were started – see figure 3).

In this state, we let the two inverters run for an hour. The compressors cycled off and on during operation and none of them had a problem restarting. After an hour, we turned off the inverters and turned them on again with the compressors on, and the whole process started without any problems.

The compressors on one wagon are not connected to the common network at the same time. Each wagon has a Control Box in which there are time relays and it is guaranteed that two or four 3x400V outputs will never turn on at the same time (one wagon can fit two large or four small containers). During the test, pairs of large containers on each car were used throughout the train.

The moment when compressors are turned on also depends on their internal circuits (thermostats, control circuits). In the case of using eight refrigerated containers, it may happen that the compressors on several wagons are switched on at the same time. During the tests, it happened that two compressors turned on at the same time, but this did not mean any failure of the output voltage.

2.3 Successive switching on of 11 to 14 containers

We connected all 6 converters one by one and tested the start-ups of the compressors. The sharing of currents took place evenly, which we monitored on three inverters using the HWM5 diagnostic program. However, we managed to make screen copies of only two converters, because we got rain into one connection from the extension USB cables and it was no longer possible to monitor three converters at once.

We gradually released 10 containers. When starting the eleventh container, we monitored the behavior of the regulators on two inverters. According to figure 9 it can be seen that the voltage regulator (blue color) and the current regulator (red color) behave identically and at the same time request the same output current (in the blue circle) and output voltage (in the red circle). The output current in this case should be, according to the calculation for 11 containers and 6 inverters (11 containers x 20A) / 6 inverters) about 36.6A. In figure 10, the current output current of the first one of the inverters can be seen in the green circle.

In the case of connecting twelve containers, the output current in this case should be, according to the calculation for 12 containers and 6 inverters (12 containers x 20A) / 6 inverters) about 40A. According to figure 9, it can be seen that the inverters distribute the loads equally. It is the same inverter load as in figure 2, where there were two inverters and four containers.

Current phase U [A]	40.9
Current phase V [A]	41.7
Current phase W [A]	40.9

Figure 9. Connection of six inverters and 12 refrigerated containers

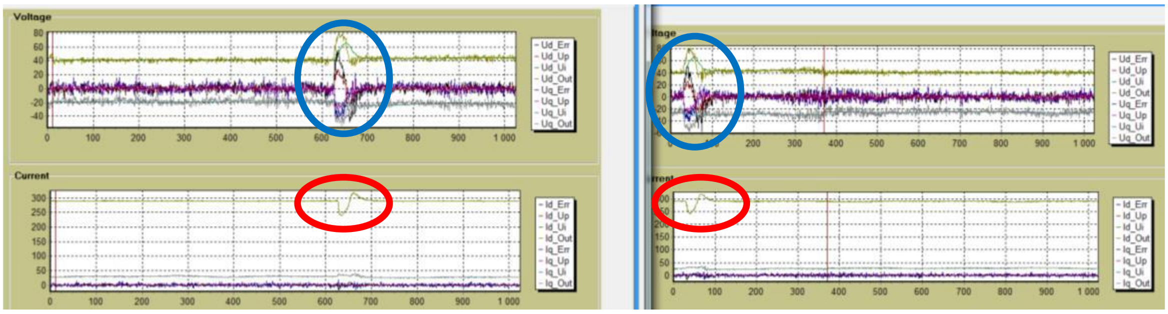


Figure 10. Behavior of SW controllers when connecting six inverters and 11 refrigeration containers

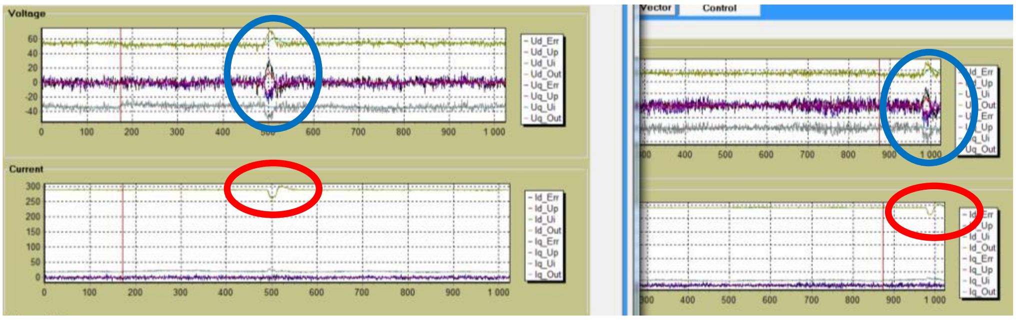


Figure 11. Behavior of the regulators when connecting six inverters and 13 refrigeration containers

Even in the case of releasing the thirteenth container, it can be seen according to figure 11, that the regulators of two of the six converters behave identically and the currents are divided equally between the 6 converters (figure 12).

Current phase U [A]	45.8
Current phase V [A]	46.8
Current phase W [A]	45.3

Figure 12. Connection of six inverters and 13 refrigerated containers

In the next picture you can see the connection of up to 14 containers, and the wagon set loaded in this way was allowed to run for more than 1 hour, and then we turned off and on the HV and all the converters started and everything started without problems (see figure 13).

Current phase U [A]	50.2
Current phase V [A]	49.3
Current phase W [A]	48.5

Figure 13. Connection of six inverters and 14 refrigerated containers

Figure 14 shows the graphical onset of the entire load. In the tenth second, all inverters (6 units) are started, and from the 40th second, all the cooling containers gradually start running. The last 14 started in the 260th second and the converters remained stable throughout the run. At some times, several containers were connected automatically at the same time, which is reflected in a higher capture current, for example at times 41s and 50s.

In the event that several compressors are already running, the inrush current from the inverter when the next compressor is turned on is not so great, because the other running motors transfer their energy to it.

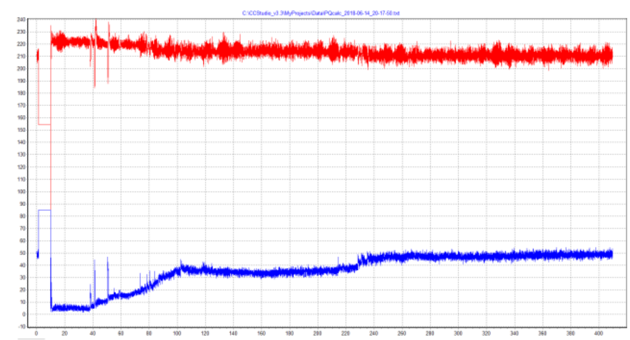


Figure 14. Graphical interpretation of the progressive load of the converter

3. Conclusions

Parallel cooperation was verified on six converters. These converters created a common continuous three-phase network 3x380V. At nominal load, according to the data from the diagnostic program, this voltage dropped to 3x355V (about 7%). We chose a setting where the desired voltage in the system was set to 380V, in order to verify the operation of the inverters even at the lower limit of the output voltage, where compressors usually draw a higher current. Due to lack of time, we could not check the operation of the converters at the nominal voltage of 3x400V.

By measuring, we verified that the division of power between the individual converters is uniform with minimal deviations. With various step changes in the load, the continuous network was stable, did not oscillate and supplied sufficient voltage to power the refrigerated containers.

By short-term switching off of HV, passage of the set through a voltage-free section was simulated. After re-discovering the HV, a continuous network was established without complication and all 14 containers connected to six inverters were up and running within 4 minutes. The time when the compressors were turned on was individual depending on the thermostats and control circuits of the compressor in the container.

The inverters were put into operation by the superior system only after the HV converter announced the completed pre-charge and confirmed the operation. In this way, the converter did not oscillate during the inverter shots, and a common three-phase network could be created within five seconds of receiving permission to operate the inverters.

Also, during the measurement, we switched off and on the individual converters, either when empty or with a loaded continuous network. We had 6 converters and 14 containers at our disposal. So we blocked one, two and three converters. The continuous network was still active and was able to power 14 compressors. In these tests, we turned off and on random containers, and verified whether the three inverters could create a solid and, above all, stable continuous network. The inverters had no problem with these load step changes and the system was stable throughout the operation of the inverters, regardless of whether there were 3, 4, 5 or 6 inverters working into the common three-phase network.

The operation of the inverters into a common three-phase network with different numbers of active inverters and different numbers of containers was documented using a copy of the screens of the HWM5 diagnostic program.

Unfortunately, we were unable to make oscilloscope recordings, as the weather was rainy throughout the measurement period and the 230V power supply for powering the oscilloscope was not provided either.

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Modelling the Influence of Service Quality of Travel Mode on Tourism Satisfaction in Lagos State, Nigeria. A Tourist-Based Perception Study

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Abstract Tourism has remained a vital component of the economies of many major destination nations around the world due to its attributed benefits and opportunities, including economic diversification, improved quality of life, revenue generation, job creation, and sustainability of the ecosystem. Tourism can only achieve all these benefits with adequate provisioning and viable operations, maintenance, and management of transport systems. Unfortunately, the provision and operations of the transport system, especially travel modes for tourism activities in Lagos State, are faced with various challenges and externalities that consequently affect tourists' experiences and intentions to recommend and revisit as well as overall tourism satisfaction. Meanwhile, there is a paucity of empirical studies on the quality of travel modes and tourism satisfactions in fast-growing cities, including Lagos, Nigeria. It is against this background that this study modeled the influence of service quality and travel modes on tourism satisfaction in Lagos State, Nigeria. This study is anchored on a cross-sectional survey research design, and a multistage sampling technique was used to administer 2,250 copies of a questionnaire to tourists across the study area. Both descriptive (frequency percentage table, weighted-mean index analysis) and inferential (binary logistic regression, BLR) statistics were used to achieve the data analysis. Major findings revealed that the majority of the respondents were male (above 60%), within the active age group of 18–53 years, and committed between 10% and 20% of their income to tourism annually. Most respondents spent most on transportation and equally rated transportation as the most complicated tourism component of their vacation in Lagos. Furthermore, findings revealed a poor rating of most of the service quality attributes of travel modes for tourism activities and aggregately rated three (reliability, trust, and empathy dimensions) out of the five evaluated dimensions as poor and unsatisfactory in meeting their expectations. However, despite the poor ratings for the service quality of travel modes, most (about 60%) are satisfied with the quality of tourism activities experienced in Lagos State. The result of the BLR model revealed that the service quality of travel modes statistically influences tourism satisfaction in Lagos State ($\chi2 = 586.893$, $p = 0.000 < 0.05$). This study concludes that there is a need to improve the service quality of travel modes, especially public transport modes, and thus recommends the best strategies to improve the service quality of travel modes for tourism activities in Lagos State, Nigeria.

Keywords Lagos State, Nigeria, service quality of travel mode, tourism activities, transport system, tourist satisfaction.

JEL R40, R49, Z30, Z32

1. Introduction

Tourism remains a vital component of the economies of many major destination cities and nations around the world [27, 29]. Considering the importance of tourism to national development, countries endowed with many natural tourist attractions and destinations continue to invest in the sector to boost not only the tourism development, experiences, image, and sustainability of tourism activities in diverse ways but also open opportunities for economic diversification, improved quality of life, and sustainability of the ecosystem [8, 26]. Ref. [23] observed that tourism has contributed immensely to the development and growth of popular destinations such as Paris (France), London (Great Britain), Rome (Italy), and Bali (Indonesia).

As one of the fastest-growing and most significant industries in the global economy, tourism contributes to job creation, revenue generation, and economic development in countries around the world [31]. The United Nations World Tourism Organization (UNWTO) reported that international tourist arrivals reached 1.4 billion in 2018, representing a 6% increase from the previous year [30, 31]. Worthwhile, the tourism industry's growing importance in the global economy has made it a key contributor to the economic growth and development of many countries. The relationship between tourism and global economic activity is multifaceted.

Accordingly, Ref. [4, 13] opined that tourism has the potential to not only create jobs and stimulate economic growth but also contribute to foreign exchange earnings and improve a country's balance of payments. In addition, Ref. [8, 26] observed that tourism has the potential to diversify the economy and reduce dependence on traditional industries, including agriculture, manufacturing, and the public health sector. Ref. [7, 31] affirmed that the importance and benefits of tourism to the global economy have been recognized by many countries, leading to increased investment in the tourism industry across the globe. For example, in 2019, China launched a project investment worth $1.4 trillion in tourism infrastructure and its development for the next five years of project completion [31]. This investment highlights the significant role that tourism plays in the global economy and that it remains a viable one, serving as a potential for continued growth and development of the tourism industry towards improving countries' gross domestic products and relative socioeconomic opportunities.

Since time immemorial, transport systems, especially the transport infrastructure, have been fundamental to the development, functionality, and sustainability of tourism-related activities across the globe. Transport systems have remained a crucial component in the growth and development of any economy and the functioning and survival of various economic sectors, including the tourism industry. Cities and every other community around the world rely on transport systems to perform both mobility and accessibility functions, such as moving materials for manufacturing goods, distributing finished goods to consumers, locating and connecting places of work, markets, business activities, leisure, religion, medical activities, and homes. Without a transport system, interaction among geographical locations, spatial units, and socioeconomic activities including tourism would be merely impossible [3, 6, 25]. However, there has been an established symbiotic relationship between tourism and the transport system, upon which various modal options such as road, rail, ferry, and aviation ensure seamless satisfaction of tourists, boosting the tourism image, and sustainability of the tourist destinations over the years. Precisely, without transport, no tourism activities can be undertaken in the right direction [17, 26]. Specifically, it is primarily saddled with the basic responsibilities of bringing the tourists and other tourism beneficiaries to the destination zones, moving around the attraction places during the period of the tour, and taking them back to their respective origins once the tour is over [26].

Despite the significant benefits of transport systems for tourism activities, they become a bane when operations and management are deluged with various challenges. Unfortunately, the level of transport system development, especially the infrastructure and travel modes for tourism activities in Lagos State, is undesirable, low, and unsatisfactory in terms of its provisions, operations, maintenance, and management. Ref. [2] observed that the travel modes that support socioeconomic functions in Nigerian cities are not only inadequately provided, but they are characterized by various operational issues that compromise their quality of service. Ref. [20] noted that the modal operations and management of travel modes across Nigerian cities and other communities faced several constraints that could be categorized under basic factor constraints, underlying factor constraints, and signs and symptoms constraints. According to Ref. [19], the major transport system challenges in Lagos State include a congested road network, poor road conditions, and insufficient public transport services. Meanwhile, Ref. [26] noted that these observed constraints, which summed up to aggravate the transport system operational and management challenges, consequently constrain Lagos State and many tourism states in Nigeria from benefiting meaningfully from the lucrative tourism industries, promoting tourism's fluctuating revenue, mitigating tourism patronage, and improving tourism's image and tourist experiences.

Consequently, the growing externalities experienced from the use of travel modes, especially the public transport modes, during tourism activities, including unpredictable travel costs, unquantified urban stress, and excessive traffic delay, among others, may overwhelm the tourists' experiences, resulting in the recommendation of Lagos as a destination, the intention to revisit, the tourism image, satisfaction, and sustainability of tourism activities in Lagos State, Nigeria. It is against this background that this study modelled the influence of service quality and travel mode on tourism satisfaction in Lagos State, Nigeria. Meanwhile, there is a paucity of empirical studies on the quality of the transport system and tourism satisfaction in Lagos State, a fast-growing city with various meaningful international standard tourist attractions known for its vibrant culture, beautiful beaches, and historical landmarks. The quest to address this gap was another reason for this study. Given these, this study examined the profile of the tourists, the travel characteristics of the tourists, the factors influencing the travel mode choice of the tourists for tourism activities, the service qualities of travel modes, and the satisfaction with the quality of tourism activities in Lagos State, Nigeria, as well as modelling the influence of the service quality of travel modes on the satisfaction with the quality of tourism activities in Lagos State, Nigeria, with the view to understanding areas of travel mode service quality that require urgent attention for improving the quality of tourism activities, which affect the tourists' satisfaction, their intention to recommend, and revisit.

2. Theoretical Review

2.1. System theory

The term "system" has meaning in every form of organized research and learning. Referring to the human body, we commonly use the terms "skeletal system", "nervous system", "digestive system", etc., and in astronomy, we talk about the solar system. In a business firm, there are production and inventory systems, as well as information systems and decision systems. In a building construction, structural and plumbing systems exist, while the relationship of man to his environmental setting can be seen in systematic terms in terms of ecosystem. As a result, the concept of system is relevant to all disciplines. Systems are made up of sets of components that work together for the overall objective of the whole [3, 5, 27]. The system approach means looking at each component part in terms of the role it plays in the large system. A particular characteristic of this approach is that it attempts to arrive at decisions not only for the individual parts or elements but for their total ordering as well, through a logical, organised arrangement of steps [11]. This involves understanding problems in terms of their detailed processes so that they can be organised for solution in a manner that can be explained and repeated.

In a sense, the system approach is simply a way of thinking and approaching problems that involves looking at the whole problem rather than concentrating on one or more parts to the exclusion of everything else [21]. A basic objective of the system approach is to discover those components whose measures of performance are truly related to the measures of performance of the overall system. Then, when the measure of performance of a component increases and all the others remain equal, the measure of performance of the total system should also be increased. Otherwise, the component is not truly contributing to the system's performance. The system theory, on the other hand, emphasizes the importance of viewing objects as whole units (systems) made up of interconnected and interacting parts, as well as maintaining an organic relationship with other environmental systems. System theory has been used to synthesize and simplify the real-world complexity of tourism-related issues [11, 21]. This is because the system theory can accommodate a variety of perspectives as it does not assume a predetermined view of tourism.

A system that has a set of elements or parts that are connected to each other by at least one distinguished principle, consisting of three main components of input, output, and external factors conditioning the system. According to Ref. [12], the tourism system consists of a tourist or traveler, generating regions or tourism destination regions, and transit routes for tourists travelling between generation and destination areas, and the travel and tourism industry (e.g., transport, accommodation, and the firms and organizations supplying services and products to tourists). Transport, therefore, is the external factor that is an integral part of the tourism system connecting the tourist from both the generating and destination regions together, represented in terms of the rate of accessibility and volume of travel for effective tourism planning, development, and sustainability. Ref. [11] used the system theory to explain the significance of the transport system in tourism development, and his study revealed that the transport system is one of the main sub-systems after tourism attractions that articulates and make possible tourism development and sustain the tourism industry. Likewise, Ref. [21] corroborates this and highlighted the importance of the actual process of travel transport as an integral part of the tourist experience, even though it is perceived as less important than the activities and pursuits of tourists in the destinations.

Accordingly, geographers are interested in the spatial expression of tourist transport as a vital link between tourist generation and tourist receiving areas. They are equally concerned with the pattern of transport facilities, including accessibility and mobility, in relation to tourist travel demands and how these different processes lead to the formulation and understanding of the pattern of tourist travel on different scales, ranging from world to national, regional, and local levels. The use of various modes of transport in getting to a tourist destination has several consequences associated with the distance traveled, the amount of time involved in travelling and the mode of transport used. Ref. [21] observed that transport infrastructure and modal operations have been acknowledged to have altered the patterns of tourist accessibility and flow volumes and consequently affected the tourists experience, satisfaction and the global tourism system's development. Thus, tourism system theory relies on the transport system at different scales to give vivid explanation and clarity of what forms of access, modes, and types of operation (e.g., scheduled and non-scheduled), spatial processes, patterns, and networks are required to facilitate tourism activities including tourist travel satisfaction, tourist destination planning, quality access, development, and sustainability.

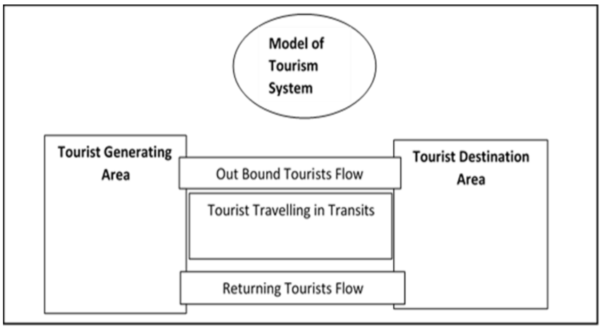

Figure 1. Tourism system [21]

3 Material and Methods

3.1 Scope of the Study

The scope of the study is discussed under location and subject scope. Specifically, this study cover the entire five (5) administrative divisions of Lagos State. It was delimited to all the local government areas with notable tourist attractions, which are mostly patronized by both local and international tourist under the five (5) administrative division of Lagos State (Fig. 1.1). The justification for selecting Lagos State is based on the fact that the state, out of the 36 states in Nigeria, only Lagos State is captured among the global most visited cities in the global destination cities assessment report. On the subject scope, the study was limited operationally to matters relating to the relationship between transport infrastructure (all available modes of transport used for or supporting tourism activities air, road, rail, water and telecommunication) and sustainable tourism issues in Lagos State. However, the study rely only on the perception of the tourists (both international and domestic) as respondents.

3.2 The Study Area "Lagos State, Nigeria"

Lagos State, which is the most populous state in Nigeria, estimated at a population figure of 15,388,00 [9], is located in the southwestern part of Nigeria on the Atlantic Coast in the Gulf of Guinea and west of Niger & River Delta at longitude $3^0$45E and latitude $6^0$35N (Figure 2). This state is bounded in the east and north by Ogun state; in the west by the Republic of Benin; and in the south by the Atlantic Ocean, which gives several opportunities for tourism and water transport potential. Lagos state is classified into five (5) five regional divisions: Ikeja, Ikorodu, Lagos Island, Epe and Badagry with twenty (20) twenty local government areas (LGA) and 57 local council development areas (LCDA) in 2003. Specifically, Lagos state is characterized by six (6) transport modes, namely road, water (inland water and maritime), air, rail, pipeline and cable transport (still under construction), with several travel means including Bus Rapid Transit and noticeable transport infrastructure. In terms of tourism potential, Lagos state is home to several attractions classified as historical monuments, beaches, museums, cultural and annual festivals, with a total score of more than 150 [9].The state is blessed with several hotels and guest apartments for tourist accommodation, which are world-class standards and equally blessed with beautiful architectural looks but with complex traffic situations.

3.3 Methods

The research methods in this study is discussed under the following sub-headings: the research design, sources of data used, study population and sample size, sampling procedure and sampling techniques, questionnaire design and reliability test, methods of data collection, method of data presentation and analysis and the postulated research hypothesis.

3.3.1 The Research Design

This study is anchored on a cross-sectional research design that combined both qualitative and quantitative approaches in achieving research objectives. The qualitative approach gave the researchers the opportunity of getting in-depth information relevant in addressing the research objectives from the sample unit that is the tourists. The quantitative approach gave the researchers the opportunity to transpose the qualitative data into quantitative data as well as analysed numerical data obtained from the sample units and used for analysis.

3.3.2 Sources of Data

This study employed data from both primary and secondary sources. The primary data was sourced through questionnaire administration on tourists and complemented by field observation. While, the secondary data was sourced through consultation of relevant published and unpublished materials that formed the literature reviewed.

3.3.3 Study Population and Sample Size

The study population comprised of the tourist population in all the notable attractions, mostly patronized by both international and domestic tourists, which amount to ninety (90) in number within the Lagos State. A total of forty-five (45), equivalent to 50% of these tourist attractions, were selected across the five (5) regional divisions of the study area as the sample frame. Meanwhile, a total of two thousand two hundred and fifty (2,250) tourists as respondents "sample units" participated in this study.

3.3.4 Sampling Procedure and Techniques

This study adopted a probability sampling procedure in achieving the research objectives, and a multistage sampling technique was used in achieving the administration of the research questionnaire. In the first stage, stratified sampling was used to identify the ninety (90) notable tourist attractions drawn across the Lagos State's five (5) regional divisions, which included Ikeja, Ikorodu, Lagos Island, Badagry, and Epe. All the tourist attractions were assigned numerical numbering to allow for possible random selection. At the second stage, simple random sampling was used in selecting fifty percent (50%) of the delineated tourist attractions in each of the regional divisions. Aggregately, a total of 45 tourist attractions were randomly picked for the study. At the third stage, a convenient sampling technique was used in sampling the tourists found available at the randomly selected tourist attractions. The opinions of the available people on visit at each selected tourist attraction were sampled to confirm those who were tourists or excursionists. In other words, those on excursion (less than 24 hours) were excluded and did not participate, while those on vacation (more than 24 hours) were encouraged to participate in the study.

3.3.5 Questionnaire Design and Reliability Test

The questionnaire was segmented into four sections with section A focusing on tourist profiles, which included location of attraction visited, sex, age, highest educational level, employment status, place of residence, nationality, average monthly income, percentage of annual income spent on tourism, and form of tourism visit etc. Section B focuses on tourist travel characteristics such as vehicle ownership, travel distance, nature of travel mode, form of travel mode, major modes of transportation used to access tourist destinations, and frequency of tourist visit. Section C contained questions on factors influencing travel modal choice for tourism ac-tivities, and Section D addressed questions on the service quality of travel modes for tourism activities and the overall satisfaction with the tourism activities in Lagos State.

The questionnaire design took the form of close-ended questions. The study used Cronbach Alpha for the reliability test, and the value of the scale used for sections C and D was 0.86 and 0.88, respectively. The content validity of the research questionnaire was confirmed by engaging twelve professionals from academic and industry. Six copies of the questionnaire were shared among professors and senior lectures within the research interests, while the remaining copies were shared among tourists and tour operators.

3.3.6 Method for Data Collection

The questionnaire instrument was used as the method of data collection method. This is complemented by researchers' field observations. The questionnaire was administered on

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carefully screened tourists found at the selected tourist attractions. The data for this study was collected between June and August 2022 in Lagos State. The questionnaire administration was conducted with the support of 12 research assistants spread across the five regional divisions of Lagos State. It is worthy to note that the research questionnaire was administered using the on-spot administration method and retrieved immediately after completion since it takes an average of 15 minutes to be completed.

3.3.7 Method of Data Presentation and Analysis

This study adopted both descriptive and inferential statistics in presenting and analysing the collected data from the field. The descriptive statistics were used in presenting the findings of objectives one to four using simple frequency and percentage distribution tables, cross-tabulation analysis, and index analysis. The index analysis that relies on the summation of weighted value SWV, relative mean index RMI, and mean index value MIV was employed on the five-point Likert's scale and a four-point Likert's scale with three (3) different forms of gradation value consisting of No at all influential =1, Slightly influential =2, Somewhat influential = 3, Very Influential = 4, and Extremely influential =5 for the five-point Likert's scale, and Strongly Disagree = 1, Disagree = 3, and Strongly Agree =4 as well as Strongly Dissatisfied =1, Dissatisfied = 2, Satisfied =3, and Strongly Satisfied =4 for the four-point Likert's scale. In line with Ref. [24], the SWV for each of the variables was obtained through the addition of the product of the number of responses to each of the indices of the variable identified and the respective weight value attached to each rating. Mathematically, it is expressed as:

$$SWV = \sum_{i=1}^{4} X_i Y_i \qquad (1)$$

Where:
SWV = Summation of Mean Weighted Value
X_i = number of respondents to rating i,
Y_i = the weight assigned a value (i= 1, 2, 3, 4)

Meanwhile, the Relative Mean Index [RMI] for each of variable was arrived at by dividing the SWV by the total number of responses. Mean Index Value [MIV] is obtained by dividing the sum of RIM by the number of examined variables. This is mathematically expressed as

$$RMI = \frac{SWV}{\sum_{i=1}^{4} X_i} \qquad (2)$$

The inferential statistical techniques of binary logistics regression were used in testing the research hypothesis which states that whether or not the quality of travel modes statistically influences the overall satisfaction with travel modes for tourism activities in Lagos state, Nigeria. The study identified 28 service quality parameters that could influence tourists' satisfaction with travel modes for tourism activities from the literature [14, 15, 18, 22, 28]. In other words, the study adopted the use of the statistical package for social sciences (SPSS) IBM version 25 for data computation and analysis.

3.4 Research Hypothesis

H_0: There is the statistical significance relationship between the service quality of travel mode for tourism activities and the overall satisfaction with the tourism activities in Lagos State, Nigeria. The research hypothesis was tested using Binary Logistic Regression.

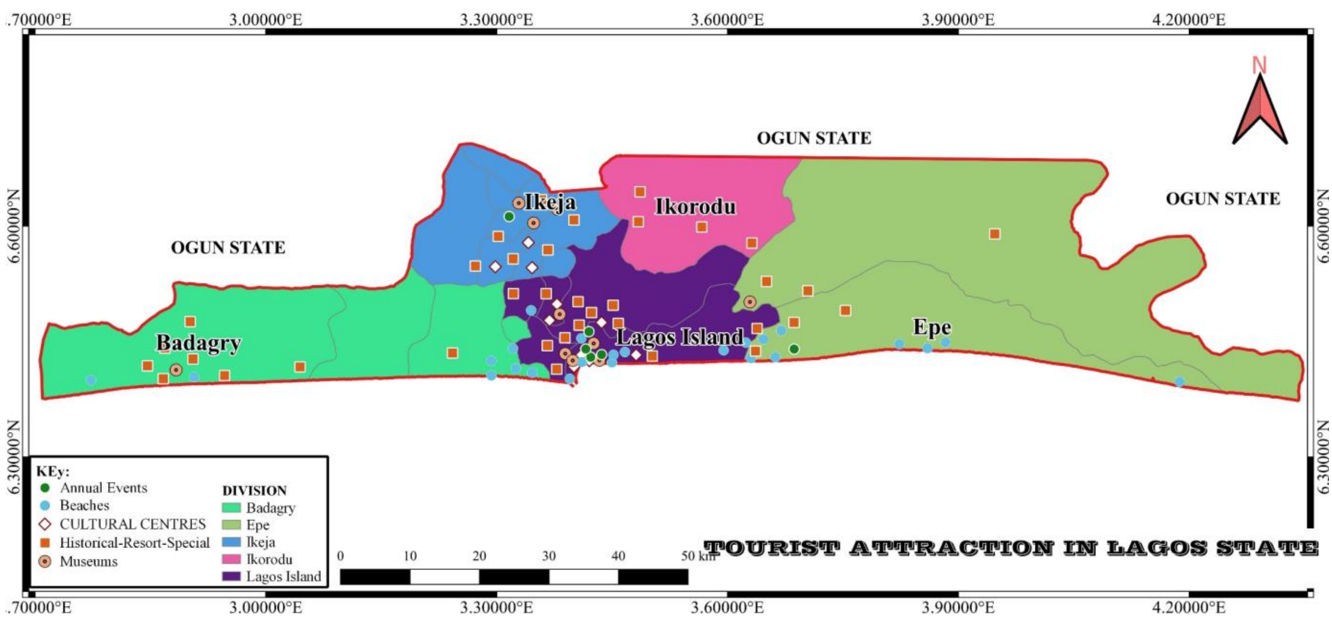

Figure 2. Lagos State showing the location of notable tourist attractions across the 5 administrative divisions

4. Results and Discussion

This sub-chapter presents the results and discussion in line with the study objectives.

4.1 Tourist Profile

Understanding the socio-economic status (SES) of tourists is important as it helps in understanding the behaviour and dispositions of the sampled tourists within the context of Lagos State, Nigeria. Table 1 presents the SES of the sample tourists, where findings on the gender, age group, educational level, employment status, marital status, average monthly income, and annual percentage of income committed to tourism were presented. The findings on the gender of the sampled tourists showed that the majority, about 60%, were male, while a slight above 40% were female. By implication, the male gender is more involved in tourism activities than their female counterparts in Lagos state, Nigeria. These findings are in tandem with the findings of Ref. [16]. Of the age groups of the respondents, the age group between 18 and 35 years accounted for more than one-third (38.5%), which was the largest. This was followed by the age group between 36 and 53 years, which represented 28.4% of the respondents. Those between the age group of 54 and 70 years accounted for less than a quarter (18.3%), while those over 70 years accounted for one-tenth (10.4%) of the respondents. The remaining 3.3% were those of the age group below 18 years and represented the least. A vivid observation of Table 1 of age distribution showed that the dominance of the respondents' age group is between 18 and 53 years, which indicates the most economically active group that represents major actors within the society.

Table 1 also revealed the educational level of respondents. A greater proportion, about half of the respondents (44.7%), were either university or polytechnic graduates, the equivalent of a first degree. This is followed by those who obtained the senior secondary school certificate, which represented a little more than a quarter (26.6%). Those who obtained a higher degree of post-graduate diploma, Masters, and or Ph.D. accounted for 22.8%, which is less than a quarter of the total respondents, while the primary school leaving certificate and its equivalent were less than one-tenth (4.4%). The remaining 1.4% of the respondents were those with no formal education, and accounted for the least group. The findings on the level of educational attainment of the sampled tourists in Lagos state indicated a high level of literacy for the respondents. This reflects the good literacy situation of tourists.

The structure of the average monthly income of the tourists in Lagos State showed that a greater proportion, and the majority, representing about half (43.5%) of the respondents, earned above N200,000 monthly. This is followed by those who earn between N150,001 and N200,000, which accounted for less than one-third (29.9%) of the respondents. Those who earned between N100,001 and N150,000 accounted for less than a quarter of the total respondents, 13.4% and 9.1%, respectively. Those who earned less than N50,000 accounted for less than one-tenth (4.1%) and represented the least dominant. By implication, these findings show that most of the respondents earn far above the national minimum wage of N30,000 per month in Nigeria and can afford to engage in tourism activities. These findings corroborate the findings of Ref. [1, 16].

Table 1 shows the percentage of income committed by the respondents to tourism. A majority of almost half of the respondents (43.7%) committed between 10% and 20% of their annual income to tourism activities. This was followed by those who committed less than 10% and between 21% and 30%, which accounted for more than one-third (36.4%) of the respondents; and more than one-tenth (13.4%), respectively. Those who committed more than 30% of their annual income to tourism accounted for less than one-tenth (6.5%) of the respondents and represented the least dominant committed income structure.

Table 1 also presents the nationality of the sampled tourists. The findings showed that a majority, more than two-thirds of the respondents (67%), are Nigerians and represented the largest group of respondents. This is followed by those who have their nationality within other African countries, which accounted for less than a quarter (19.1%), while the least number of respondents are those who are not Nigerians or from other African countries but from countries outside Africa. They accounted for 13.1%, which is more than one-tenth of the total sampled respondents. By implication, it is clear to report that the sample of tourists is spread across both international and domestic tourists.

The results on the form of tourism visited by the respondents were equally presented in Table 1. The findings showed that the majority of tourists on recreational/leisure visits accounted for more than two-thirds of the respondents (68.0%), representing the most dominant form of tourism visit in Lagos State. This is followed by those tourists on business visits, which accounted for more than one-tenth (10.2%) of the respondents. Those who came for sports/adventure-related visits, historical/cultural visits (educational related visits), and medical/health-related visits also accounted for less than one-tenth of the respondents, 8.1%, 7.9%, and 5.0%, respectively. Those who accounted for the least type of tourism visit were those whose religion-related visits represented less than 1% (0.8%). By implication, the nature of tourism attractions in the state, especially the beaches and the resorts, which are quite unique to the study area, attracts more visitors. Hence, the findings of this study differ from the findings of Ref. [16]

Table 1. Tourists Profile

Tourists Profile	Lagos Island		Ikorodu		Ikeja		Badagry		Epe		Grand Total	
Gender	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**
Female	435	19.3	42	1.9	195	8.7	108	4.8	133	5.9	913	40.6
Male	615	27.3	58	2.6	155	6.9	242	10.8	267	11.9	1337	59.4
Sub-total	1050	46.7	100	4.4	350	15.6	350	15.6	400	17.8	2250	100.0
Age Group	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**
Less than 18 years	15	7.0	4	0.2	17	0.8	15	0.7	24	1.1	75	3.3
18-35 years	297	13.2	13	0.6	106	4.7	179	8.0	271	12.0	866	38.5
36-53 years	262	11.6	61	2.7	147	6.5	102	4.5	90	4.0	662	28.4
54-70 years	258	11.5	17	0.8	70	3.1	54	2.4	13	0.6	412	18.3
Above 70 years	218	9.7	5	0.2	10	0.4	0	0.0	2	0.1	235	10.4
Sub-total	1050	46.7	100	4.4	350	15.6	350	15.6	400	17.8	2250	100.0
Educational Level	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**
No formal education	7	0.3	7	0.3	5	0.2	8	0.4	5	0.2	32	1.4
Primary	65	2.9	9	0.4	18	0.8	4	0.2	4	0.2	100	4.4
Secondary	295	13.1	11	0.5	76	3.4	103	4.6	114	5.1	599	26.6
First degree	373	16.6	20	0.9	176	7.8	194	8.6	242	10.8	1005	44.7
Higher degree	310	13.8	53	2.4	75	3.3	41	1.8	35	1.6	514	22.8
Sub-total	1050	46.7	100	4.4	350	15.6	350	15.6	400	17.8	2250	100.0
Average Monthly Income	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**
Less than ₦50,000	41	1.8	29	1.3	2	0.1	9	0.4	12	0.5	93	4.1
₦50,000 - ₦100,000	154	6.8	11	0.5	27	1.2	9	0.4	4	0.2	205	9.1
₦100,001 - ₦150,000	104	4.6	7	0.3	75	3.3	58	2.6	58	2.6	302	13.4
₦150,001 – ₦200,000	269	12.0	26	1.2	114	5.1	113	5.0	150	6.7	672	29.9
Above ₦200,000	482	21.4	27	1.2	132	5.9	161	7.2	176	7.8	978	43.5
Sub-total	1050	46.7	100	4.4	350	15.6	350	15.6	400	17.8	2250	100.0
Percentage of Income Committed to Tourism	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**
Less than 10%	377	16.8	43	1.9	108	4.8	145	6.4	147	6.5	820	36.4
10% - 20%	511	22.7	38	1.7	121	5.4	153	6.8	160	7.1	983	43.7
21% - 30%	114	5.1	11	0.5	71	3.2	36	1.6	69	3.1	301	13.4
Above 30%	48	2.1	8	0.4	50	2.2	16	0.7	24	1.1	146	6.5
Sub-total	1050	46.7	100	4.4	350	15.6	350	15.6	400	17.8	2250	100.0
Nationality	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**
Nigerian	786	34.9	67	3.0	275	125.2	288	12.8	111	4.9	1527	67.9
Other African	87	3.9	27	1.2	19	0.8	41	1.8	255	11.3	429	19.1
Non-African	177	7.9	6	0.3	56	2.5	21	0.9	34	1.5	294	13.1
Sub-total	1050	46.7	100	4.4	350	15.6	350	15.6	400	17.8	2250	100.0
Form of Tourism Visit	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**
Recreation/leisure	704	31.3	1	0.0	197	8.8	308	13.7	319	14.2	1529	68.0
Cultural/historical	16	0.7	29	1.3	53	2.4	42	1.9	38	1.7	178	7.9
Medical/health-related	35	1.6	25	1.1	34	1.5	0	0.0	19	0.8	113	5.0
Sport/Adventure	83	3.7	45	2.0	31	1.4	0	0.0	24	1.1	183	8.1
Business	194	8.6	0	0.0	35	1.6	0	0.0	0	0.0	229	10.2
Religion	18	0.8	0	0.0	0	0.0.	0	0.0	0	0.0	18	0.8
Sub-total	1050	46.7	100	4.4	350	15.6	350	15.6	400	17.8	2250	100.0

4.2. Travel Characteristics of Tourists

Worthwhile, understanding the travel characteristics of tourists tangential to understanding the vacation travelers' behavior. Importantly, Table 2 presents the results of the travel characteristics of the sampled tourists during their vacation to Lagos State. On the insight into the respondents' choice of travel mode used to access the destination city for the vacation. Individuals that used public transport accounted for more than half (56.8%) of the respondents and represented the majority. The remaining percentage accounted for those who use private transport to get to their destinations. By implication, most of the tourists on vacation in Lagos State cannot do without public transport usage.

The results on the distribution of respondents on the form of transport for the tourism activities in Lagos State showed the dominance of the mono mode, that is, the use of a single mode of transport to accomplish their activities during the vacation, which represented 50.4%. This is closely followed by those who use intermodal transport services, that is, the use of more than one means of transport, which accounted for more than one-third (35.1%) of the respondents. Those who visited using multimodal, which accounted for less than a quarter (14.6%), represented the least. Table 2 also presented the distribution of respondents' length of stay for the vacation. Respondents who booked for 2 days, which accounted for more than one-third (36.70%), represented the majority. This is closely followed by those who were staying for 3 days and above, which accounted for more than a quarter (33.7%) and less than a quarter (20.5%) respectively. The remaining percentage, which accounted for less than one-tenth (9.1%), are those staying for a day (one night), representing the smallest group. By implication, sample respondents have at least an overnight stay at or around the attraction during the vacation, thus confirming their true nature of being tourists and not excursionists.

Furthermore, Table 2 presented the distribution of the distance covered from home to the destination by the respondents. It is interesting to note that those who traveled and covered over 80 km from home to the destination, which accounted for more than one-third (38.2%), presented the most dominant. This is closely followed by those who cover between 61 and 80km, 41 and 60km, and 20 and 40km, which accounted for less than a quarter of the total, 21.4%, 19.8%, and 11.7%, respectively. Those who spent less than 20 km from their home to the destination accounted for less than one tenth (8.9%) and represented the least dominance.

The results on the distribution of the respondents on major travel means used to access the tourist destinations of interest within the study area were presented in Table 2. The findings showed that those who used private car or SUV to access their interested attractions in the destination city “Lagos State”, which accounted for more than one-third of the respondents (39.5%), represented the most dominant travel means. This is followed by those who navigated the tourist attractions by bus, ride hailing, ferry/boat, mini-bus, and power bike/motor cycle, which accounted for less than a quarter of 16.9%, 15.6%, 12.5%, 11.8%, and 3.7%, respectively. It is interesting to note that no tourists travelled by BRT or trains to access their destinations. By implication, the BRT and train facilities are not linked to major tourist attractions mostly visited by tourists.

Table 2. Travel Characteristics of Tourists

Tourists Profile	**Lagos Island**		**Ikorodu**		**Ikeja**		**Badagry**		**Epe**		**Grand Total**	
Length of Stay	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**
1 day	70	3.1	17	0,8	69	3.1	36	1.6	13	0.6	205	9.1
2 days	530	23.6	46	2.0	117	5.2	80	3.6	52	2.3	825	36.7
3 days	337	15.0	27	1.2	87	3.9	134	6.0	173	7.7	758	33.7
Above 3 days	113	5.0	10	0.4	77	3.4	100	4.4	162	7.2	462	20.5
Sub-total	1050	46.7	100	4.4	350	15.6	350	15.6	400	17.8	2250	100.0
Distance Covered to Destination	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**
Less than 20km	33	1.5	10	0.4	5	0.2	101	4.5	51	2.3	200	8.9
20-40km	48	2.1	17	0.8	70	3.1	39	1.7	89	4.0	263	11.7
41-60km	121	5.4	7	0.3	119	5.3	68	3.0	131	5.8	446	19.8
61-80km	309	13.7	15	0.7	80	3.6	22	1.0	55	2.4	481	21.4
Above 80km	539	24.0	51	2.3	76	3.4	120	5.3	74	3.3	860	38.2
Sub-total	1050	46.7	100	4.4	350	15.6	350	15.6	400	17.8	2250	100.0
Nature of Mode for the Visit	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**
Private transport	532	23.6	15	0.7	215	9.6	148	6.6	62	2.8	972	43.2
Public transport	518	23.0	85	3.8	135	6.0	202	9.0	338	15.0	1278	56.8
Sub-total	1050	46.7	100	4.4	350	15.6	350	15.6	400	17.8	2250	100.0
Form of Transport Used	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**
Mono	431	19.2	14	0.6	231	10.3	220	9.8	237	10.5	1133	50.4
Intermodal	462	20.5	55	2.4	83	3.7	67	3.0	122	5.4	789	35.1
Multimodal	157	7.0	31	1.4	36	1.6	63	2.8	41	1.8	328	14.6
Sub-total	1050	46.7	100	4.4	350	15.6	350	15.6	400	17.8	2250	100.0
Major travel means Used to Access Tourist Attractions	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**
Power bike/ motorcycle	67	3.0	0	0.0	14	0.6	1	0.0	1	0.0	83	3.7
Ferry/ boat	175	7.5	8	0.4	70	3.1	14	0.6	14	0.6	281	12.5
Car/SUV	354	15.7	90	4.0	140	6.2	151	6.7	154	6.8	889	39.5
Mini-bus	179	8.0	2	0.1	24	1.1	29	1.3	32	1.4	266	11.8
Bus (organized group)	102	4.5	0	0.0	65	2.9	85	3.8	129	5.7	381	16.9
Charter flight	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Ride hailing	173	7.7	0	0.0	37	1.6	70	3.1	70	3.1	350	15.6
Train (organized group)	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Bus Rapid Transit	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Sub-total	1050	46.7	100	4.4	350	15.6	350	15.6	400	17.8	2250	100.0

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4.3Factors Influencing the Travel Mode for Tourism Activities

Table 3 presents the findings on the factors influencing the modal choice of tourists for tourism activities in Lagos State using the Likert's scale measurement, which were graded based on five (5) points captured as: Not at all Influential = 1, Slightly Influential = 2, Somewhat Influential = 3, Influential = 4, and Extremely Influential = 5. The respondents were made to assess the factors that influence their travel mode for tourism activities in Lagos state and their responses were analyzed. From Table 3 presented, ten (10) factors were analyzed using Weighted Index Analysis in line with equations 1 and 2 presented in the methodology. The analysis produced a relative mean index of 30.076 and a mean index value of 3.0077 (Table 3). A close review of table 3 shows that 7 factors out of the ten (10) evaluated have a Relative Mean Index (RMI) greater than the MIV. According to the findings, the majority of the factors, more than two-thirds (70%), are good fits to influence respondents' modal choice for tourism activities along and within the destinations, while the remaining less than one-third are less influential factors.

Specifically, findings presented in Table 3 revealed that the choice of destination (3.9898), safety and security of travel mode (3.7080), and comfort and convenience of travel mode (3.5573) ranked as the top-three most influential factors among the ten (10) evaluated factors influencing modal choice for tourism activities. This is closely followed by travel mode availability (3.3924), length and nature of journey (3.3676), access to travel information (3.3924), and travel mode affordability (3.2760). However, the level of information available on tourism activities (2.0036), speed of travel mode (2.0000), and the organization of travel mode and trip characteristics were the least ranked influential factors affecting the decision on modal choice for tourism activities. By implication, the choice of the travel mode for tourist activities in Lagos State is greatly influenced by the choice of the destination in terms of where and how the destination or attractions activities are prepared, planned, and situated. These findings corroborate the study carried out in developed cities of the European continent as revealed by Ref. [10, 14, 30]. The safety and security level of the travel mode, the comfort and convenience of the travel mode are also crucial factors that influence modal choice for tourism activities, availability of the mode, the length and nature of the journey, the accessibility to travel information, as well as the affordability of the travel mod

Table 3. Factors Influencing the Travel Modal Choice for Tourism Activities

Factor	No at all influential	Slightly influential	Somewhat influential	Very Influential	Extremely influential	TWV	RIM	MIV	MD	RK
Length and nature of journey	227	680	1011	4284	1375	7577	3.3676		0.36	5
Affordability of travel mode	222	950	2121	608	3470	7371	3.276		0.27	7
Organisation of travel mode and trip	1535	812	927	0	0	3274	1.4551		-1.55	10
Speed of mode	1072	880	1587	336	625	4500	2.0000		-1.01	9
Comfortability and convenient of travel mode	384	892	483	200	6045	8004	3.5573	30.0769/10= 3.0077	0.55	3
Access to information	443	272	1164	3232	2375	7486	3.3271		0.32	6
Availability of transport mode	466	436	588	2828	3315	7633	3.3924		0.38	4
Choice of destination	19	424	492	4932	3110	8977	3.9898		0.98	1
Level of information available	1346	686	405	236	1835	4508	2.0036		-1.00	8
Safety and security of transport mode	116	634	1956	752	4885	8343	3.7080		0.70	2

4.4 Service Quality of Travel Modes and Satisfaction with Tourism Activities

4.4.1 Service Quality of Travel Mode

The service quality of travel modes for tourism activities was examined based on the perception of tourists using a Travel Mode Service Quality Index (TMSQI). The parameters used to develop the TMSQI were adopted and modified from the existing literature [14, 15, 18, 22]. Table 4 presents the findings on the service quality of travel modes for tourism activities (TMSQI) in Lagos State using the Likert's Scale measurement, which were graded based on four (4) points captured as strongly disagree = 1, strongly disagree = 2, agree = 3, and strongly agree = 4. Twenty-eight (28) variables across five (5) dimensions [Tangibility (6), reliability (6), responsiveness (5), trust (5), and empathy (6)] were analyzed using Weighted Index analysis in accordance with equations 1 and 2 in the methodology. The analysis produced a weighted sum of 65.2550 and a mean index value (MIV) of 2.3305 for the TMSQI (Table 4)

Findings on the tangibility dimension revealed 5 out of 6 (90%) parameters in the TMSQI ranked above the MIV. It further revealed that the majority of the sampled tourists ranked travel modes with sufficient and comfortable seating (3.2818) as first, while travel modes with up-to-date facilities (1.9831) as the least quality of service of travel modes under tangibility. By implication, all travel modes are equipped with comfortable seating, but the facilities, including the seats and information, are not updated. Findings on the reliability dimension revealed that 2 out of 6 (one-third) ranked above the MIV. It further revealed that travel modes are dependable and do not breakdown (2.6280) and travel modes are timely and follow the route plan and schedules (1.4862) as the first and least service quality variables under the reliability of travel modes, respectively. By implication, travel modes do not breakdown and are dependable, but with poor transit time and route planning. Next to this is the findings on the responsiveness dimension, which revealed 3 out of 5 (60%) variables in the TMSQI ranked above the Mean Index Value MIV. Findings revealed that the majority of the respondents ranked terminal maintenance and support facilities in good condition for effective service delivery (2.5471) as the first and travel modes providing ease of ticketing and seat allotment (1.9076) as the least service quality variables under responsiveness. From these findings, it can be deduced that the travel modes are with good and well-maintained terminals, but ticketing and seating within the terminal are still poor. Findings on the trust dimension revealed 2 out of 5 (more than one-third) of the variables as a measure of TMSQI ranked above the MIV. Findings also revealed that the majority of tourist-ranked travel modes are not overcrowded enough to make the trip unpleasant (3.4044) and that travel modes provide up-to-date information on travel and traffic situations (1.6729) as the first and least variable service quality under trust. By implication, it can be deduced that travel modes in the study area are not overcrowded but are without updated travel and traffic information under the trust dimension. Findings on the empathy dimension revealed 1 out of 5 (less than a quarter) variables in the TMSQI ranked above the MIV. Table 4 further revealed that the majority of the tourists ranked travel modes according to frequency of service on various routes (3.3680) and travel modes with entertainment facilities (1.915) as the 1st and least service quality variables and empathy. From the findings, it can be deduced that although travel modes maintain a frequency of service on various transit routes, they do not have enough entertainment facilities, such as television and radio, to make trips pleasurable.

A vivid observation of Table 4 on the assessment of the TMSQI revealed that a half-equivalent to 50% of the total evaluated parameters (28) ranked above the MIV of 2.3305. The findings show that the travel modes available for tourism activities in Lagos state are: not overcrowded to make trips unpleasable (3.4044); maintains frequency of service on various routes (3.3680); maintains sufficient and comfortable seating (3.2818); drivers appear friendly, neat, and smart (2.9262); accessible to all categories of tourists (2.8516); drivers behaviour install safety and confidence in passengers (2.6844); dependable and does not breakdown (2.6280); spacious, safe, and comfortable (2.5862); terminals' maintenance and supportive facilities are in good condition for effective service delivery (2.5471); modal services are always available (2.5342); appropriate number of stops with shield (2.4636); service providers and drivers are trained and responsive (2.4520); vehicles' condition is good, neat, with an odorless interior (2.4298); and with facilities that are always readily available for use (2.3618), both of which scored above the MIV and ranked 1st-14th). However, four variables were ranked below the MIV of 2.3305, including: travel modes are timely and operationally effective for tourism activities (2.2227); environmentally friendly (2.1480); transport information is readily available and easily accessible by tourists (2.1356); passenger interest and satisfaction are prioritized (2.0676); are with up-to-date facilities and operational information (1.9831); with affordable fare charges (1.9640); with adequate functional entertainment facilities (1.9151); provide ease of ticketing and seat allotment (1.9076) and maintain security measures against crime (1.9049). Other parameters with the lowest rankings are: travel mode maintaining a timely and straight procedure for handling complaints (1.8369); maintaining a special treat for vulnerable groups (1.7600); with a timely and effective complaints handling procedure at the terminal (1.7316); providing information on travel and traffic situations (1.6729); and timely and following the route plan schedules (1.4862). Furthermore, it is interesting to note that the quality of service of the existing travel modes for tourism activities in the study area is of poor service quality and unsatisfactory as three (3) out of the five (5) evaluated service quality dimensions (reliability, trust, and empathy), an equivalent 60%, are rated as unsatisfactory, while the remaining 40% are rated satisfactory, which are tangibility and responsiveness of travel mode. Hence, the service quality of these modes does not meet the expectations of tourists. The reason for the increasing use of personal cars and vehicles for tourism activities in Lagos state is not far-fetched from the findings. To achieve sustainable tourism activities, there is a need to improve the quality of services offered by travel modes, most especially the public transport modes which area always appropriate for choice and captive riders tourists and other tourism beneficiaries.

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Table 4. Service Quality of the Travel Mode

Factor	SD	D	A	SA	TWV	RIM	MIV	MD	RK
Tangibility: Travel mode is accessible to all categories of tourists	556	292	1872	3696	6416	2.8516		0.52	1
Travel mode is spacious, safe and comfortable	801	94	2052	2872	5819	2.5862		0.26	8
Travel mode is in good condition, neat with odorless interior	910	94	2127	2336	5467	2.4298		0.10	13
Drivers appear friendly, neat and smart	442	172	2754	3216	6584	2.9262		0.60	4
Travel mode maintains sufficient and comfortable seating	34	18	4488	2844	7384	3.2818		0.95	3
Travel mode is with up-to-date facilities and information	1217	472	1245	1528	4462	1.9831		-0.35	19
Reliability: Travel mode is timely, follows up the route plan/schedule	1686	394	612	652	3344	1.4862		-0.84	28
Travel mode is dependable and does not breakdown	681	8	3108	2116	5913	2.6280		0.30	7
Travel mode fare charges are affordable	1339	76	1464	1540	4419	1.9640		-0.37	20
Service providers and drivers are trained and responsive	878	246	1809	2584	5517	2.4520		0.12	12
Complaints-handling procedure at terminal is time effective	1288	946	882	780	3896	1.7316		-0.60	26
Maintains timely and straight procedure for handling complaints	1277	726	930	1200	4133	1.8369		-0.49	24
Responsiveness: Travel mode service is always available	685	436	2421	2160	5702	2.5342		0.20	10
Travel mode service is timely and operational effective	980	520	1617	1884	5001	2.2227		-0.11	15
Travel mode provide ease of ticketing and seats	1269	604	891	1528	4292	1.9076		-0.42	22
Travel mode terminals maintenance and supportive facilities are in good condition for effective repair and service delivery	763	400	1740	2828	5731	2.5471		0.22	9
Travel mode has appropriate number of stops with shield	807	456	1740	2540	5543	2.4636		0.13	11
Trust: Travel mode maintains security measures against crimes	1114	986	1158	1028	4286	1.9049		-0.43	23
Drivers behavior install safety and confidence in passengers	585	432	2319	2704	6040	2.6844		0.35	6
Travel mode is not overcrowded to make trip unpleasable	22	160	3342	4136	7660	3.4044		1.07	1
Travel mode provide information on travel and traffic situation	1425	860	303	1176	3764	1.6729		-0.66	27
Travel mode maintains a special treat for vulnerable groups	1305	898	681	1076	3960	1.7600		-0.57	25
Empathy: Transit information is readily available and easily accessible	1043	582	1452	1728	4805	2.1356	65.2553/ 28 = 2.3305	-0.19	17
Passenger interest and satisfaction is prioritized	1006	616	2142	888	4652	2.0676		-0.26	18
Travel mode facilities are always readily for use	832	434	2268	1780	5314	2.3618		0.03	14
Travel mode maintain frequency of service on various routes	20	230	3396	3932	7578	3.3680		1.04	2
Travel mode is environmental friendly	1033	596	1416	1788	4833	2.1480		-0.18	16
Availability of entertainment facilities (radio, TV)	1148	826	1263	1072	4309	1.9151		-0.42	21

4.4.2 Satisfaction with the quality of tourism activities

Further investigations were conducted to establish tourists' satisfaction with the quality of the experienced tourism activities in Lagos State, Nigeria, and the results of this analysis are presented in Table 5 based on the regional delineation and aggregate scores. It is interesting to note that findings on regional delineation showed that the majority of the respondents—over 60%—were satisfied with the quality of tourism activities in Lagos Island (65%), Ikeja (64%), and Epe (62%), while more than half of the respondents were not satisfied with the quality of tourism activities in Ikorodu (51%), and Badagry (74%). In summary, more than half (over 57%) of the respondents were satisfied with the quality of tourism activities in Lagos State, Nigeria, while the remaining 43% were not satisfied with the quality tourism activities in Lagos State. The reason for the relatively close percentage between those who were satisfied (57%) and unsatisfied (43%) is not far-fetched from the poor tourism experience, which is directly linked to the complex traffic situation and unpredictable cost of transportation, unavoidable mobility difficulties, and complex and corrupt immigration and customs procedures. By implication, the quality of travel mode and tourism activities, affects the expectations and satisfaction tourists as well as affects their experience and tourism image of Lagos State.

Table 5. Overall satisfaction with quality of tourism activities

Overall Satisfaction with quality of tourism activities	Lagos Island		Ikorodu		Ikeja		Badagry		Epe		Grand Total	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Strongly Dissatisfied	88	3.9	19	0.8	46	2.0	136	6.0	38	1.7	327	14.5
Dissatisfied	282	2.5	32	1.4	81	3.6	124	5.5	114	5.1	633	28.1
Satisfied	490	21.8	24	1.1	172	7.6	65	2.9	184	8.2	935	41.6
Strongly Satisfied	190	8.4	25	1.1	51	2.3	25	1.1	64	2.8	355	15.8
Sub-total	1050	46.7	100	4.4	350	15.6	350	15.6	400	17.8	2250	100.0
Sum of Weighted Value	5818											
Mean	2.5858											

Source: Authors' fieldwork, 2022

4.5 Hypothesis Testing

Hypothesis statement in null form:

H0: There is no significant relationship between the service quality of travel modes and the overall satisfaction with the quality of tourism activities in Lagos State

In a bid to test the postulated hypothetical statement three, which is examined to understand the statistically significant relationship between the service quality of travel modes and the overall satisfaction with the quality of tourism activities in Lagos State, Nigeria, further investigations were conducted using binary logistic regression (BLR) analysis. The logit regression analysis measures and defines the relationship between the dependent variable and independent variables as it establishes and explains the extent of the relationship between a binary outcome and a group of predictors, or independent variables. In other words, the BLR Analysis was used to determine whether or not there is a statistically significant relationship between the service quality of travel modes and the overall satisfaction with the quality of tourism activities. That is, it established the extent to which the tourists' overall satisfaction with the quality of tourism activities is explained by the quality of travel modes for tourism purposes in the study area. The dependent variable, which is the variable to be predicted (tourists' overall satisfaction with tourism activities), was dichotomously recoded and transformed into dummy or binary variables of 0 and 1 (from the four-point Likert's scale as very dissatisfied/dissatisfied = 0 and satisfied/very satisfied = 1). The independent variables or predictors (the service quality of travel mode), which are twenty-eight (28) variables captured under five (5) dimensions (tangibility, reliability, responsiveness, trust, and empathy), were also transformed to a dichotomous binary digit of 0 and 1 (strongly disagree/disagree = 0 and agree/strongly agree = 1). In other words, using the variable defined above, the logit regression equation for this hypothetical statement is expressed as:

$$\text{Logit (y)} = Log\left\{\frac{P}{IP}\right\} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + --- + \beta_{28} X_{28} \ldots(3)$$

Where:

Logit (y) = the binary outcome dependent variable indicating failure or success of the overall tourist satisfaction with quality of tourism activities

$\beta 1, \beta 2, \beta 3, \beta 4, \beta 5 \ldots\ldots\ldots\ldots\ldots.. \beta 28$ = the parameters of the model

$X_1, X_2 X_3, X_4, X_5$ ……………… X_{28} = the predictors or the independent variables

P= the probability of failure or success of the independent variable.

It is worth knowing that the model, through the goodness-of-fit statistics (omnibus tests of model coefficients), explained the chi-square results and significance values presented in Table 6, was used to determine where the model adequately describes the data in the model and explain the overall significance of the predictors' variables in the BLR analysis. Significantly, the results show a chi-square value of 586.893, which reaches a significant level with a p-value of 0.000 less than the table value of 0.05 alpha level. From this analysis, it is crystal clear that the dependent variable (overall tourists' satisfaction with the quality of tourism activities) is statistically significantly predicted by the predictor variables. Given this, the model is showing a good fit. This implies that there is a statistically significant relationship between the service quality of the travel modes and the overall tourist satisfaction with the quality of tourism activities. Hence, these findings established that the overall satisfaction with the quality of tourism activities in Lagos State, Nigeria, is statistically significantly explained and predicted by the service quality of the travel modes (or is a function of the service quality of the travel modes) for tourism activities in Lagos State, Nigeria. The decision on this hypothetical statement is to accept H1 (the alternative hypothesis) and reject H0 (the null hypothesis). By implication, the better the service quality of the travel mode for tourism activities, the more satisfaction the tourists would derive from the tourism activities in the study area. Thus, the greater the satisfaction with tourism activities, the greater the intention to return and recommend them, as well as the tourism image of Lagos State, Nigeria.

Furthermore, the findings through the mode summary show the Cox & Snell R Square and NagelKerke R Square results in Table 6, sometimes referred to as the pseudo-R Square value, and explain similar results and findings of the R Square and Adjusted R Square in multiple regression analysis to show the level of explained variation in the dependent variable. In other words, the Cox & Snell R Square value shows 0.320 and NagelKerke R Square shows 0.409. As a result, the explained variation in the dependent variable ranges from 32% to 41% of Cox & Snell R-square and NagelKerke R-square, respectively, indicating a strong relationship between predictors and the outcome, that is, a strong relationship between the service quality of travel modes and overall satisfaction with the quality of tourism activities, as shown in Table 6.

Also, the results presented under the classification table in Table 6 explain the modal prediction level. In other words, Table 6 shows the percentage of cases correctly classified and predicted by the model, as well as the percentage of cases established from the dependent variable assessed, as well as the effectiveness of the predicted classification versus the actual classification. Hence, the results from the classification table show that 592 are observed to be 1 (very satisfied and satisfied) and are correctly predicted as 1. 1,014 cases are observed to be 1 (very satisfied and satisfied) but predicted to be 0, 289 cases are observed to be 0 (very dissatisfied and dissatisfied) and are correctly predicted as 0, and 335 cases are observed to be 0 but predicted as 1. In summary, the overall percentage of the cases correctly predicted by the model is 71.4, indicating that the model was able to classify 71% of all the cases correctly.

Furthermore, the results displayed under the variables in the equation table presented in Table 6 show the contribution of each independent variable to the models through the Wald Test in the Wald column. The Wald Test results explain the significant and non-significant predictor variables that contribute to the model at the alpha level of 0.05. From the results, 18 variables out of the twenty eight (28) predictors contributed significantly to the model prediction, while the remaining 10 predictors didn't contribute significantly to the model prediction. By implication, this findings revealed that a unit change and improvement in the service quality of travel modes which include travel mode is spacious, safe and comfortable (TANGSPACIOUS2, Sig. = 0.011), driver appear friendly, neat and smart (TANGFRIEND4, Sig. = 0.000), travel mode is timely and follow the root plan/schedule (RELTIME7, Sig. = 0.001), travel mode is dependable and does not breakdown (RELDEPEN8, Sig. = 0.000), service providers and drivers are trained and responsive (RELSERVEPROV10, Sig. = 0.000), complaints-handling procedure at the terminal is timely and effective (RELHAND11, Sig. = 0.000), maintain timely and straight procedure for handling complaints (RELMAINT12, Sig. = 0.046), travel mode service is always available (RESPMODESERVICE13, Sig. = 0.000), travel mode is timely and operational effective (RESPTIMELY14, Sig. = 0.000), travel mode provide ease of ticketing and seat allotment (RESPEASETICK15, Sig. = 0.000), travel mode terminals, maintenance and supportive facilities are in good condition for effective service delivery (RESPTERMINAL16, Sig. = 0.008), travel mode has appropriate number of stop with shied (RESPOAPPRSTOPS17, Sig. = 0.000), driver behaviour install safety in passenger/tourist (TRUSTBEHAV19, Sig. = 0.000), travel mode provide information on travel and traffic situation (TRUSTTRAFFICSITU21, Sig. = 0.000), travel mode maintain a special treat for vulnerable group (TRUSTSPECIALTREAT22, Sig. = 0.000), transit information is readily available and easily accessible (EMPTRANSITINFO23, Sig. = 0.033), travel mode facility are always readily available for use (EMPFACIL25, Sig. = 0.000), availability of entertainment facility (EPNENTERTAIN28, Sig. = 0.000) will increase overall satisfaction with tourism activities in Lagos State. Improvements in the tangibility, dependability, responsiveness, trust, and empathy of the travel mode for tourism activities along and within destinations will thus increase satisfaction with tourism activities in the study area.

Table 6. Binary logistic regression of the statistical relationship between the service quality of travel mode and the overall satisfaction with the quality of tourism activities in Lagos State

omnibus Tests of Model Coefficients				
		Chi-square	Df	Sig.
Step 1	Step	586.893	28	.000
	Block	586.893	28	.000
	Model	586.893	28	.000
Model Classification				
		Overall satisfaction with travel mode (Predicted)		
		Strongly Dissatisfied/Dissatisfied (0)	Satisfied/ Strongly Satisfied (1)	Percentage Correct
Overall satisfaction with travel modes (Observed)	Strongly Dissatisfied/Dissatisfied (0)	1014	289	77.8
	Satisfied/ Strongly Satisfied (1)	335	592	62.5
Overall Percentage				71.4
Model Summary				
Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square	Step
1	2475.705[a]	.320	.409	1
a. Estimation terminated at iteration number 5 because parameter estimates changed by less than .001.				

Variables in the Equation							
Step 1[a]		B	S.E.	Wald	Df	Sig.	Exp(B)
	TANGACCESS1	.181	.116	2.436	1	.119	1.198
	TANGSPACIOUS2	.244	.135	3.263	1	.041	1.276
	TANGGOODCOND3	-.134	.138	.944	1	.331	.874
	TANGFRIEND4	-.705	.142	24.708	1	.000	.494
	TANGTRAVELMODEMA5	.464	.373	1.548	1	.213	1.590
	TANGFACI6	-.008	.123	.004	1	.950	.992
	RELTIMELY7	.533	.161	11.027	1	.001	1.704
	RELDEPEN8	-.662	.121	29.915	1	.000	.516
	RELFARE9	.060	.127	.227	1	.634	1.062
	RELSERVPROV10	.588	.121	23.686	1	.000	1.801
	RELHAND11	-.744	.142	27.389	1	.000	.475
	RELMAINT12	.372	.186	3.994	1	.046	1.450
	RESPMODESERVICE13	1.012	.123	67.664	1	.000	2.752
	RESPTIMELY14	-1.080	.131	68.291	1	.000	.340
	RESPEASETICK15	.485	.133	13.277	1	.000	1.625
	RESPTERMINAL16	.304	.115	6.977	1	.008	1.356
	RESPOAPPRSTOPS17	.845	.132	41.040	1	.000	2.328
	TRUSTSECMEANS18	-.188	.129	2.119	1	.145	.829
	TRUSTBEHAV19	.576	.123	22.052	1	.000	1.778
	TRUSTOVERCOW20	.518	.304	2.895	1	.089	1.678
	TRUSTRAFFICSITU21	.633	.144	19.438	1	.000	1.884
	TRUSTSPECIALTREAT22	.847	.133	40.456	1	.000	2.334
	EMPTRANSITINFO23	.295	.139	4.527	1	.033	1.344
	EMPASSENGERINT24	-.196	.132	2.228	1	.136	.822
	EMPFACIL25	-.437	.117	14.005	1	.000	.646
	EMPFREQMODE26	-.333	.260	1.643	1	.200	.717
	EMPENVFRIENDL27	.058	.122	.231	1	.631	1.060
	EMPENTERTAIN28	.928	.123	56.775	1	.000	2.530
	Constant	-2.270	.558	16.524	1	.000	.103

5. Conclusion and Recommendations

This study revealed and concluded that the quality of service of travel modes is a pre-condition for sustaining tourism activities through tourists' satisfaction in Lagos State, Nigeria. Adequate provision, planning, regulation, and management of operations, as well as adequate facility maintenance of travel modes would: facilitate tourist ease of accessibility to and out of destinations; provide quality transport services within the destinations; boost tourism image; enhance tourists' intention to visit and revisit destinations; improve ease of linkage and fulfilment of tourist demands to tourism support facilities and services including accommodation, shopping, and other hospitality requirements not only in Lagos State but in both other states in Nigeria with similar tourism potential. Despite these, it is worth knowing from the major findings of this study that tourists are not satisfied with the quality of services and travel modes available for tourism activities in Lagos State. Although the tourists are fairly satisfied with the tangibility and responsiveness dimensions of the service quality of the travel mode, they mostly found the dimensions of the reliability, trust, and empathy of travel modes to be of poor service quality and thus not satisfactory. Meanwhile, the findings of the hypothetical statement show that the variables in the model that are the parameters of the service quality of travel mode best predict the overall satisfaction with travel modes of tourism activities in the study area. Therefore, there is a need for urgent and huge investment in technical and measures to improve the quality of travel modes in Lagos State towards mitigating the challenges attributed to travel modes' performance, such as congestion, unpredictable cost of commuting and travel time, and poor accessibility of travel public transit for tourism activities, as well as to benefit tremendously from the potential attributed to tourism activities.

To achieve an increased tourist's satisfaction with tourism activities and facilitate sustainable tourism through improved service quality travel modes in Lagos State, Nigeria, there is a need for immediate action on measures to minimize both the operational characteristics and management issues attributed to the existing travel modes. These measures include continuous improvement in transport infrastructure provision that would facilitate efficient service quality of the travel modes, especially reliability, trust, and empathy; strengthening the implementation of transport and traffic policies; collaboration of transport and tourism institutions in projects and program development and execution that would improve the quality of tourism activities through travel modes; and involvement of private participation in infrastructure support provision and investment; and establishing a special institutional framework for tourist transport planning. The Lagos State would improve its tourism attractiveness to both domestic and international tourists, resulting in an increase in international arrivals, overnight stays, revenue generation, tourism image, and tourism contribution to GDP.

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Data acquisition unit for road vehicle or aircraft

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Abstract Data acquisition is a critical aspect of modern vehicle and aircraft design, as it provides engineers and researchers with essential information on the performance and behaviour of these vehicles in various operating conditions. In this paper, we present a data acquisition unit (DAU) for road vehicle or aircraft that utilizes various sensors, including GNSS, INS, RPM measurement, barometric altimeter, and ESP32 microcontroller. The DAU consists of multiple sensors, including a GNSS receiver to determine the vehicle's position, speed, and heading. An inertial navigation system (INS) is used to measure the vehicle's acceleration and angular rate. RPM sensors are used to measure engine speed, and a barometric altimeter is used to measure the altitude of the vehicle. An ESP32 microcontroller is used to acquire, process, and store the data from these sensors. In the end the design and utilisation of DAU was success gaining data for research in field of road and air transport.

Keywords GNSS, INS, RPM

JEL L63, L93

1. Introduction

With the advancement in technology, the use of Internet of Things (IoT) devices has become prevalent in different domains, including aviation [1] and automotive industries. IoT devices have the potential to provide real-time data, which can improve the safety, efficiency, and performance of these industries. In this paper, we present an IoT-based Data Acquisition Unit (DAU) for aircraft and road vehicles. In aircraft sector the data could be provided to the OGN platform [2] and [3]. The proposed DAU is designed to collect data from different sensors, including Global Navigation Satellite System (GNSS), Inertial Navigation System (INS), barometric altimeter, and RPM measurement from voltage ripple. The collected data is transmitted to a remote server for further analysis and processing. The paper is structured as follows. Section 2 presents the architecture of the proposed DAU, followed by Section 3, which discusses the design of the DAU. Section 4 presents the experimental results, and finally, Section 5 concludes the paper.

2. Architecture of the Proposed DAU

The architecture of the proposed DAU is shown in Figure 1.

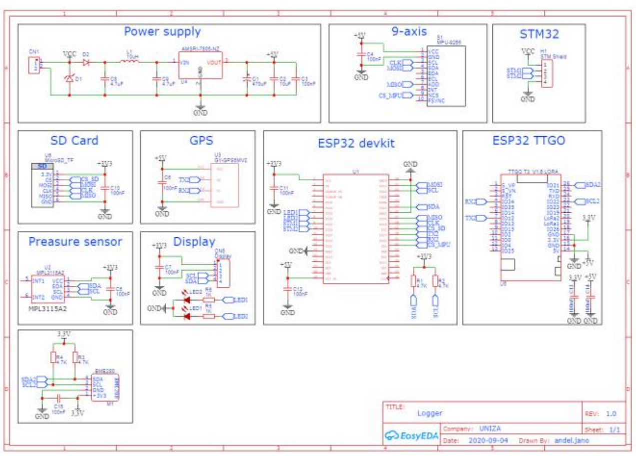

Figure 1. Schematic diagram of the DAU [5].

The design was based on [4] and [5]. The DAU consists of different modules, including a power supply module, a data acquisition module, a data processing module, a communication module, and a control module. The power supply module provides power to the DAU, which can be

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either from the aircraft or vehicle's electrical system or a standalone battery.

The data acquisition module consists of different sensors, including GNSS, INS, barometric altimeter, and RPM measurement from voltage ripple, which collect data in real-time [6].

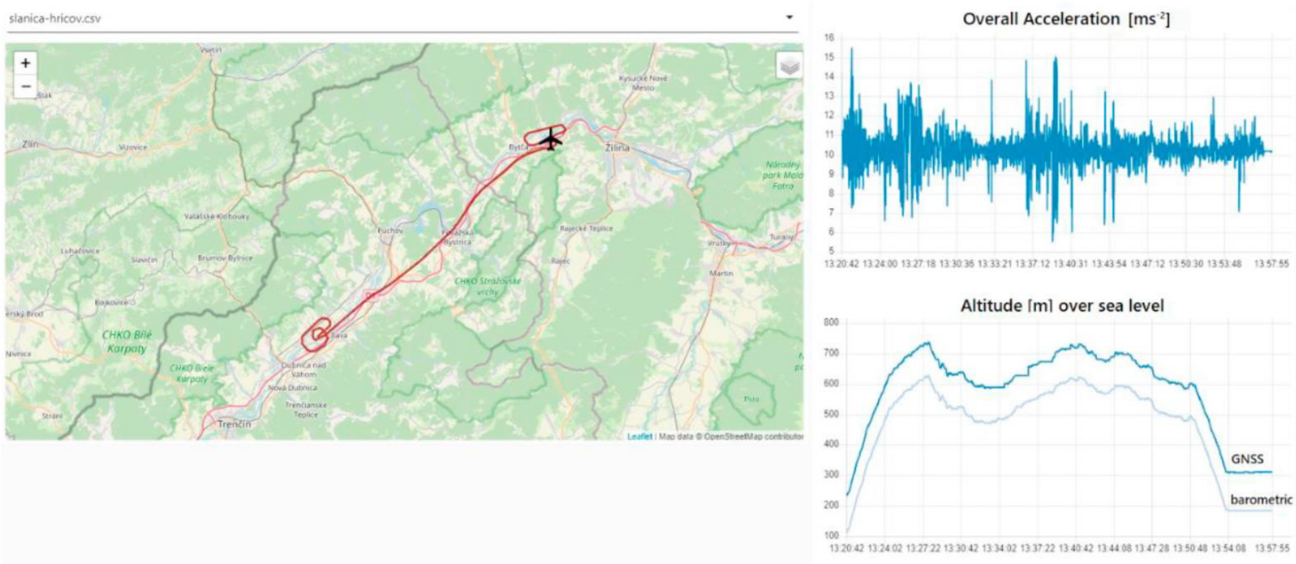

Figure 2. Data recorded by the unit during flight from airport Slávnica (Dubnica nad Váhom) to Žilina airport in Dolný Hričov (airplane L13SE Vivat reg. OM9112) [5].

The data processing module processes the collected data and prepares it for transmission to the remote server. The communication module establishes a connection with the remote server and transmits the data. Finally, the control module manages the operation of the DAU.

3. Design of the DAU

The design of the DAU is based on an Arduino micro controller board. The microcontroller board is connected to different sensors through a sensor shield. The sensor shield provides a plug-and-play interface for the sensors, which simplifies the integration of the sensors with the microcontroller board. The microcontroller board is also connected to a Wi-Fi module, which is used for communication with the remote server transmission (see Figure 3).

The GNSS sensor provides the location, velocity, and time data, which are essential for navigation. The INS sensor provides the attitude, velocity, and acceleration data, which are essential for navigation and control. The barometric altimeter provides the altitude data, which is essential for navigation and control.

The collected data is processed by the microcontroller board and prepared for transmission to the remote server. The data is transmitted using the HTTP protocol, which is widely used for web communication. The remote server receives the data and stores it in a database for further analysis and processing.

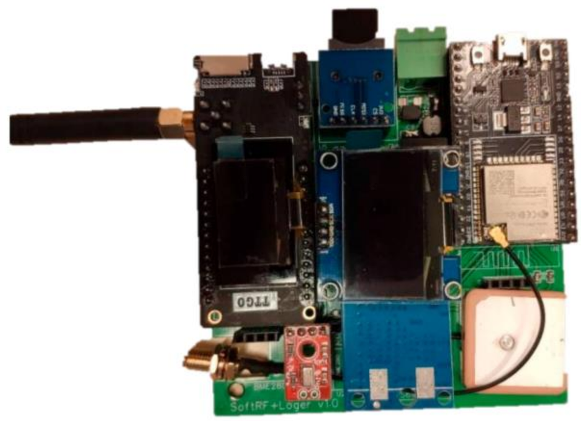

Figure 3. Complete DAU [5]

4. Experimental results

The proposed DAU was tested on a small aircraft and a car. The DAU successfully collected data from the different sensors and transmitted it to the remote server. The collected data was analysed, and the results showed that the DAU can provide real-time data, which can be used for navigation, monitoring, and control.

An measurement of voltage ripple was also performed on 8th of July 2020 airplane Zlin 226 reg. OM-LWA. Figure 4 shows the ripple of 27V mains in airplane by 2000 RPM. The resulting ripple of voltage was cca 300 mV pp.

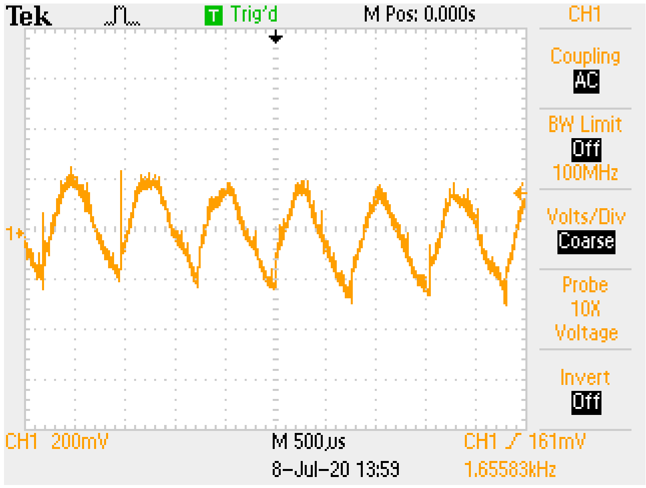

Figure 4. Voltage ripple caused by aircraft engine electrical generator

5. Conclusions

In this paper, we presented an IoT-based Data Acquisition Unit (DAU) for aircraft and road vehicles.

The proposed DAU is designed to collect data from different sensors, including GNSS, INS, barometric altimeter, and RPM measurement from voltage ripple.

The collected data is transmitted to a remote server for further analysis and processing. The experimental results showed that the proposed DAU can provide real-time data, which can improve the safety, efficiency, and performance of aircraft and road vehicles. The proposed DAU can be further improved by adding more sensors and improving the communication protocol for more efficient data transmission. In conclusion, a data acquisition unit that incorporates GNSS, INS, RPM measurement, and a barometric altimeter can provide valuable data on the position, speed, altitude, and orientation of a road vehicle or aircraft. The ESP32 is one example of a low-cost microcontroller that can be used to implement a DAU with these sensors..

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GNSS Spoofing – Advanced Mechanisms of Detection

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Abstract GNSS spoofing is a technique used to deceive Global Navigation Satellite Systems (GNSS) receivers by broadcasting fake signals that appear to be genuine. To detect GNSS spoofing, a receiver can use various techniques such as monitoring signal strength, cross-checking data from multiple satellites, comparing the signal characteristics with the expected patterns, and analyzing the timing and location information. Advanced detection methods may use machine learning algorithms to identify anomalies and patterns in the signal data. In addition, the use of encrypted signals and multiple frequency bands can make spoofing more difficult, and the implementation of spoofing-resistant hardware and software can further enhance detection capabilities. In this article various techniques of manipulation and detection of spoofing and experiments are described. There is no 100% method for spoofing detection.

Keywords GNSS, Spoofing, Jamming, Detection

JEL L63, L93, R41

1. Introduction

GNSS jamming is common illegal attack on availability of these services. Many systems are affected during jamming attack (navigation, emergency services, road, train, aircraft, ship transport, army, telecommunications etc.). Jamming is used by for example car thieves avoiding localization systems gain and transmit the correct position. GNSS jamming devices are cheap and available on internet market. Besides jamming, spoofing is more complex attack on integrity of these services. Nowadays GNSS chips are equipped with basic spoofing detection. During spoofing a wrong position is transmitted to receivers. This article will deal with more complex manner of spoofing detection.

Global Navigation Satellite System (GNSS) technology has become an integral part of our daily lives. It is used in various applications, such as navigation, transportation, and time synchronization [1] and [6]. However, the widespread use of GNSS technology has also made it vulnerable to attacks, such as spoofing. Spoofing is a type of attack where a malicious entity broadcasts a signal to deceive GNSS receivers. In this article, we will discuss the concept of GNSS spoofing, its effects, and the techniques used to prevent it.

The concept of GNSS spoofing involves broadcasting a signal that is intended to deceive a GNSS receiver. This can be done by generating a signal that is like the signal broadcast by GNSS satellites. The spoofing signal can be stronger than the genuine signal, causing the receiver to lock onto the spoofed signal. Once the receiver is locked onto the spoofed signal, the attacker can manipulate the receiver's output, causing it to provide incorrect information to the user.

The effects of GNSS spoofing can be severe. In transportation, it can cause accidents by manipulating the location of vehicles. In aviation, it can cause a plane to deviate from its course, leading to a crash. In maritime navigation, it can cause ships to run aground or collide with each other. Spoofing can also be used to manipulate time synchronization, causing errors in financial transactions and communication systems..

2. Basic spoofing detection

All modern GNSS receivers are equipped with basic spoofing detection algorithms. This is called as “receivers autonomous integrity monitoring” (RAIM). This is based on several features of spoofing signal. These properties could be divided into basic groups:

- **Based on time synchronization**. The time difference between GNSS time and spoofing signal time could be evaluated as spoofing presence. Based on authors experiments, if receiver starts with real signal and then receives spoofing signal, the signal is recognized as spoofing. The same applies vice versa. Some receivers are equipped with (Chip-Scale Atomic Clock) CSAC. Once synchronized, the receiving unit has increased capabilities of time comparison.
- **Stepwise changes in satellite position**. Satellites position is used in receiver for computation of receiver’s

position. This could not swap instantly from one position to another.

- **Multiple GNSS services**. Nowadays receivers have multiple receiving units for GPS, GLONASS, Beidou and Galileo. Since the data from one service differs from another two or three, it could be evaluated as a spoofing attack.

2.1. Manner of detection

For example Ublox 8 chips are capable to detect some spoofing attempts. The sentence UBX-NAV-STATUS gives under “flags2” the “spoofDetState” the information about spoofing attempts to fool the receiver. The mechanism is the data consistency check within one epoch. If the receiver is aligned to a genuine satellite signal, the spoofing attempt must be very sophisticated (the receiver detects stepwise changes in satellite position and timing). If the receiver has possibilities of multiple GNSS services, the spoofing detection works. If the receiver has only a single service and the receiver wakes up to an already spoofing polluted area, and the signal is consistent, there is no chance to detect the falsified signal.

3. The Experiment

We performed this experiment in the laboratory of the Department of Multimedia and Information and Communication Technologies. (setup at Figure 1) Used equipment was a Spirent GSS6700 GNSS simulator.

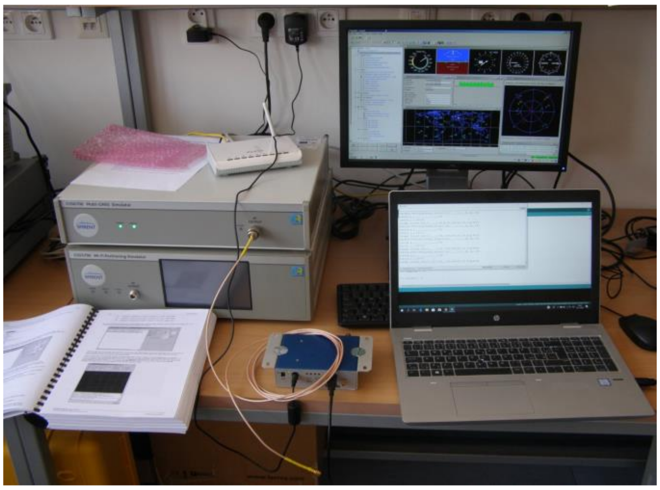

Figure 1. Setup for GPS spoofing experiment, for safety reasons the output of the generator is connected directly with the receiver, not radiating the signal.

With the help of this device, it is possible to simulate the civil part of navigation services and create a signal that would be received by the antenna in the case of a simulated trajectory. This simulator allows us to simulate different signal levels from in-dividual satellites, simulate any time, latitude, longitude, altitude, etc. For safety reasons, the receiver was directly connected to the simulator by a coaxial cable, to avoid leakage (signal transmission) and influence (spoofing) of other receivers. The device GPS Trimble Condor (70291-15) was used as the receiver. The receiver is connected to a computer that records messages composed of NMEA protocol sentences. The Spirent simulator enables the simulation of various signal changes, in this experiment we set a flight at an altitude of 500 m.a.s.l. towards the east at a speed of 50 m/s (180 km/h).

Example of a message received via the antenna (real GPS):

$GPGGA,070030.000,4912.1532,N,01845.3512,E,1,8,1.03,415.4,M,42.1,M,,*57

$GPGSA,A,3,16,29,05,31,26,25,20,21,,,,,1.65,1.03,1.29*01

$GPGSV,3,1,10,21,83,183,18,26,68,254,30,16,49,302,16,29,36,087,30*75

$GPGSV,3,2,10,20,27,163,24,27,17,282,,05,13,036,27,31,12,216,33*74

$GPGSV,3,3,10,25,07,148,27,10,05,176,*74

$GPRMC,070030.000,A,4912.1532,N,01845.3512,E,0.04,113.18,200100,3.3,E,A*0A

Example of a message received from the simulator (spoofed GPS) evaluated as correct:

$GPGGA,001053.000,4913.0010,N,01911.5073,E,1,7,1.18,459.6,M,42.0,M,,*5B

$GPGSA,A,3,10,29,23,02,13,04,24,,,,,,1.46,1.18,1.75*03

$GPGSV,3,1,11,02,81,328,45,04,50,084,44,10,39,217,44,13,31,066,44*7A

$GPGSV,3,2,11,23,17,039,43,29,12,313,43,24,06,274,43,12,,,44*49

$GPGSV,3,3,11,05,,,44,30,,,44,17,,,42*7F

$GPRMC,001053.000,A,4913.0010,N,01911.5073,E,97.19,90.01,200100,3.9,E,A*01

Example of a message received from the simulator (spoofed GPS) evaluated as incorrect:

$GPGGA,071839.000,,,,,0,1,,,M,,M,,*4D

$GPGSA,A,1,,,,,,,,,,,,,,,*1E

$GPGSV,3,1,10,21,85,103,,26,66,232,,16,56,295,,20,35,160,*78

$GPGSV,3,2,10,29,29,093,,27,24,286,,10,12,175,,05,08,032,43*76

$GPGSV,3,3,10,31,06,212,,15,01,095,*74

$GPRMC,071839.000,V,,,,,2.78,136.87,200100,3.3,E,N*27

3.1. Real GNSS spoofing attack

This incident was recorded in Black Sea in 22nd of June 2017 [2] and [3]. Several GPS receivers on a ship showed the same location on a land and evaluated it as true position signal (Figure 2).

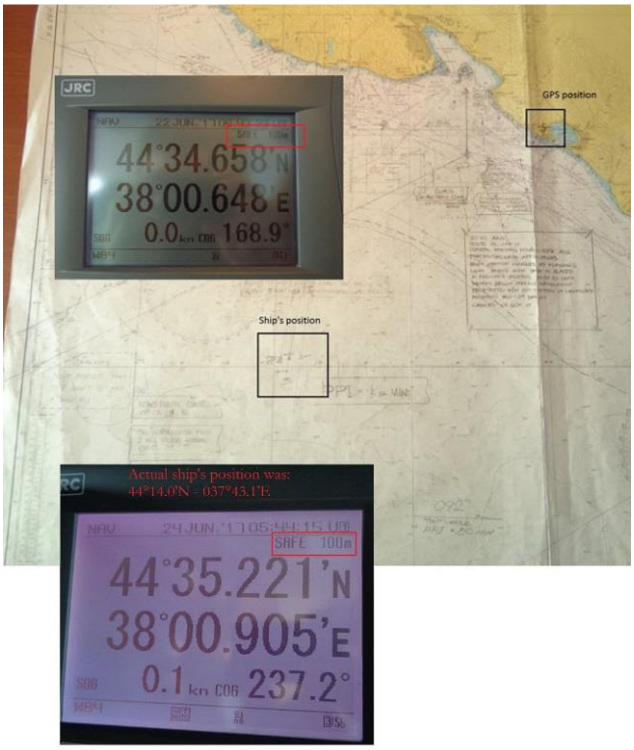

Figure 2. The example of real spoofing attack. [2]

4. Advanced spoofing detection

More complex receivers equipped with multiple antennas could apply spatial filtering for jamming or spoofing signal [4]. Relying only at GNSS signal from one point receiver the spoofing detection methods are exhausted. There are available other methods to detect abnormality in received GNSS signal leading to conclusion that the receiver is under spoofing attack:

- **Mathematical model of possible movement**. If there is movement outside the expected parameters, the received signal could be evaluated as falsified. Some NMEA sentences also contain velocity and direction information. Depending on vehicle type the behaviour scheme could be created. For ex-ample, train could not undergo acceleration exceeding some limits (ordinary train could not accelerate in 4 seconds to 100 km/h).
- **Data fusion** of GNSS with INS, GSM, barometric altimeter, odometer… This system calculates its position and speed. If a vehicle receives vertical climb from GNSS and altimeter data remains still, its suspicious. If a vehicle receives movement and INS doesn't undergo any acceleration, it's also suspicious.
- **Sensor network**. If sensor nodes are sharing its position between each other and they have another location, then it's possible to detect a spoofing attack. Example of such a sensor network is Waze application (Figure 3). Sensor nodes are sharing its position in real time. In the case of spoofing attack, all nodes in certain area will send the same location (what is impossible). Even jamming attack will be possible to detect, in the case that all nodes in area affected by jammer will lose their position simultaneously.

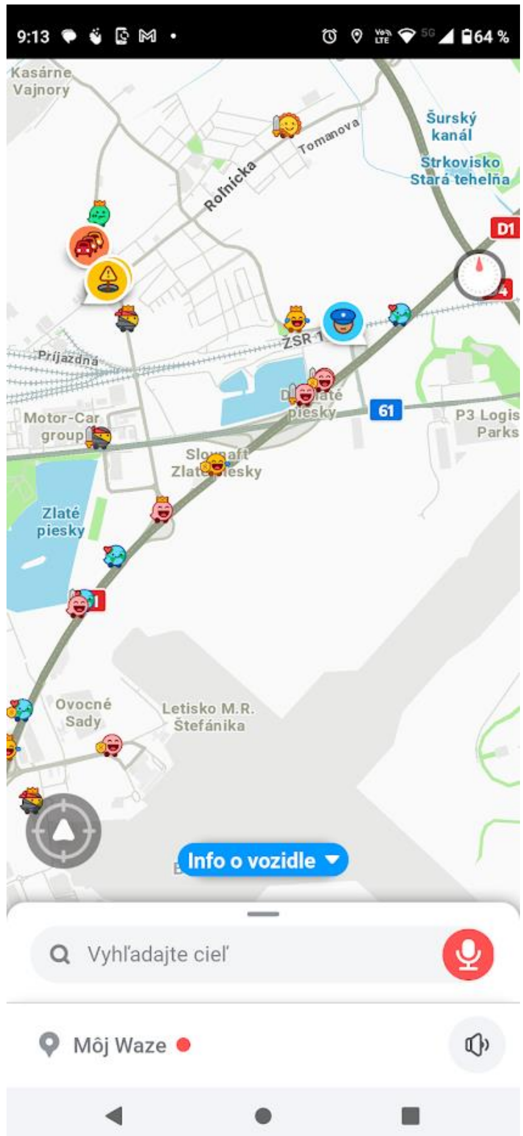

Figure 3. The example of sensor network application Waze

5. Conclusions

In conclusion, GNSS spoofing is a serious threat to the widespread use of GNSS technology. The effects of spoofing can be severe, causing accidents and errors in financial transactions and communication systems. However, there are several techniques that can be used to prevent GNSS spoofing, including signal authentication, multi-constellation receivers, and spatial filtering. By using these techniques, we can ensure the safety and reliability of GNSS technology in various applications.

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