CREATION OF REMOTE TERMINAL CONTROL SET AS A PART OF LABORATORY SCADA SYSTEM

Dobri Cundev[1] ,Vasilija Sarac[1]and Goce Stefanov[1]

[1] Faculty of Electrical Engineering, University “Goce Delcev” - Stip, Republic of Macedonia

***Abstract* — This paper shows a solution for crating of remote terminal control set (RTCS) which is used as main control and data acquisition unit for laboratory working set. This unit is just a part of complex SCADA system of laboratory testing stand for new type of hybrid-electric car propulsion system. The purpose of this control unit is acquisition of electrical quantities and real-time control of entire experimental stand.**

***Index terms*—data acquisition, SCADA, interference, motor drives, real-time control**

1. INTRODUCTION

New type of hybrid-electric vehicle (HEV) is tested in laboratory conditions in order to acquire information about its performance. Experimental working stand has been created in the laboratory in order to be performed laboratory testing of this HEV concept. The scheme of this laboratory stand is shown on Figure 1.

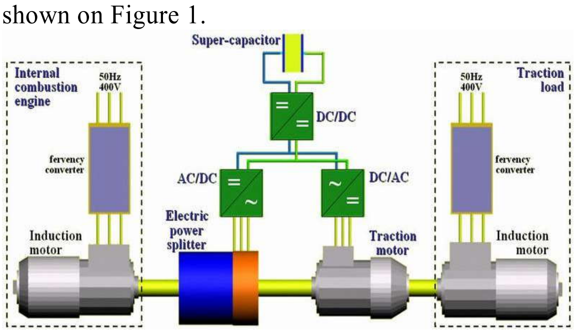

Fig. 1 Laboratory experimental stand of new type of hybrid-electric car propulsion system

On this HEV laboratory model, internal combustion engine (ICE) and the car wheels has been substituted with two regulated induction motors. Produced power P_{ice} and rotations n_{ice} of ICE drive-shaft are simulated by an AC induction motor controlled with frequency converter (FC). This converter regulates power and rotations according to demanded ICE working performance. Traction load (brake) is simulated with another controlled AC induction motor. It produces braking torque M_{brake} on the shaft proportional to the expected braking resistance of the traction load. By this means, it is created laboratory test stand for testing of the hybrid-electric car components and technology, without using actual vehicle.

There are two rotating shafts. First is ICE shaft on which are connected the ICE (controlled induction motor) and rotor of the EPS. Second shaft is traction shaft, on which are connected rotating stator of EPS, traction motor and induction motor (brake). During operation, these two shafts are mechanically independent and only EPS magnetic field is connection between them.

HEV working stand is consisted of four electrical machines, five semiconductor power control units, super-capacitor and all the necessary instrumentation, control, power supply and protection equipment. The electrical machines (two induction motors, electric power splitter and traction motor) are shown on Figure 2:

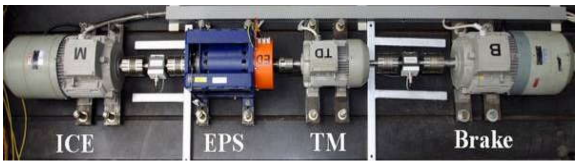

Fig. 2 Electrical machines of the laboratory stand

Rest of the working stand, two Danfoss frequency converters, power control units (traction AC-DC, DC-DC and DC-AC converters), control and power switches, electrical quantity transducers, instrumentation, condition indicators e.g. are functionally interconnected and placed into the equipment and instrumentation cabinet of the laboratory working stand (Figure 3).

HEV laboratory stand is consisted of electric drives, power electronics and associate electrical equipment. On the working stand, there are not included traditional automotive components like real internal combustion engine, changing gear, car wheels etc. Entire experimental approach is based on traditional power electrical engineering using electrical drives.

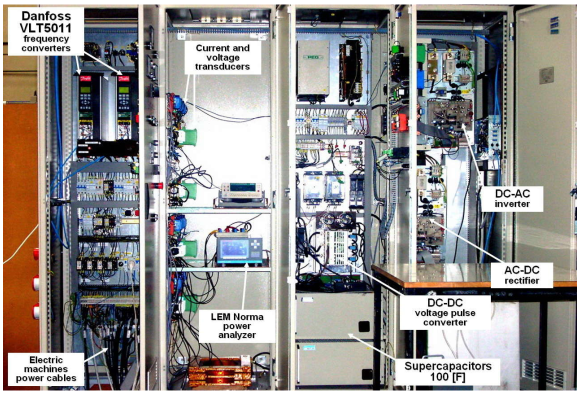

Fig. 3 Equipment and instrumentation cabinet of the laboratory working stand

2. CREATION OF THE HEV-SCADA SYSTEM

HEV working stand can be efficiently used only if there is supervisory system that gives real-time information of all essential parameters of the stand. In addition, real-time control is necessary for synergetic use of all functional entities of the stand. Creating of driving regime of a real vehicle is only possible if this functional integration is fully operational. Supervisory control is also needed for performing of predetermined driving schedule.

Significant complication in central integrated control and data transfer is electromagnetic interference (EMI). Power control units works with different modulation frequency up to 20[kHz]. In the power circuits, the current can reach value up to 600[A] and also there are significant number of active elements like high capacity capacitors and inductors. This environment generates significant EMI, which creates disturbance that may interrupt, degrade or limit the effective performance of the control circuits. Those can results with systematic errors in measured signals, wrong control command execution or obstruction of entire experimental process.

HEV experimental stand is exceedingly complex laboratory system. It has numerous different electrical and mechanical values that must been controlled and regulated. As it is explained, all the measuring equipment works as individual and independent sets. Also, the microcontrollers of the power converters are regulated independently by separate PCs without any possibility of common interaction. The Danfoss frequency converters are also individually regulated. Significant problem for creation of integrated measurement and control system is lack of data-exchange interlink among the regulated devices. Therefore, supervisory control and data acquisition system SCADA is created for HEV experimental stand (HEV-SCADA). The communication infrastructure and functional subsystems of this SCADA system are shown on Figure 4:

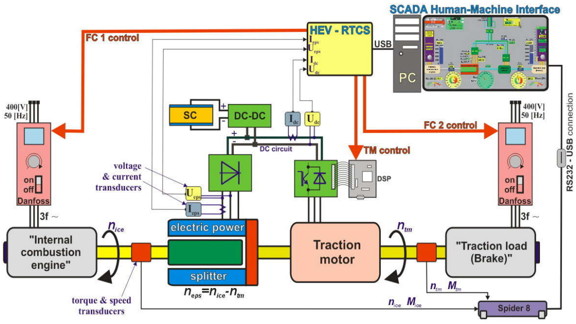

Fig. 4 HEV-SCADA measure, communication and control infrastructure

The main intelligent part of the SCADA is a supervisory computer system that gathers signal data, analyses acquired real-time information from the stand and sends feedback control commands to the process. This subsystem is consisted of PC based platform with Windows XP/Vista operating system with possibility for working on another operating system. Using standardized computer structure enables versatility of this SCADA system to be used in any PC based platform and gives options for further development and flexible upgrade according to the actual future needs of the HEV stand.

Significant contribution of creating this SCADA for the HEV working stand is enabling user-friendly human-machine interface (HMI) for the operating personnel. A HMI is the apparatus that presents process data to a human operator and through this the operator monitors and controls the process. By this means, the whole working stand can be operated with only one person. Operation controls are user-friendly and entire control is from one PC. The operator can perform numerous tests, gathering real-time data and receiving instant analyzed results.

For creation of the HEV-SCADA is used the software package LabVIEW 8.6. It provides a graphical programming environment for developing sophisticated measurement, test, and control systems. Human-machine interface for HEV is created within this software system. The main control and visualization panel which functionally is active graphic user interface (GUI) is shown on Figure 3.8. For HEV-SCADA are created many GUI panels for detail visualization, monitoring and control of specific processes of HEV stand.

LabVIEW is used as a platform because it enables intuitive graphical programming for advanced analysis and data visualization. It offers universal and versatile equipment integration with hardware devices and provides built-in libraries. This characteristics enables integration of the remote terminal unites Spider8 and HEV-RTCS.

3. HEV REMOTE TERMINAL CONTROL SET (HEV-RTCS)

Remote Terminal Unit (RTU) is a microprocessor controlled electronic device which interfaces objects in the physical world to a distributed control system or SCADA system by transmitting telemetry data to the system and/or altering the state of connected objects based on control messages received from the system. Two remote terminal units are used in HEV-SCADA for connecting the sensors in the process, converting sensor signals to digital data and sending digital data to the supervisory system. First RTU is used for acquisition of electrical and second RTU is for acquisition mechanical quantities.

For data acquisition of the electrical quantities is constructed special remote terminal unit. Sensor signals from voltage and current transducers are acquired by using two NI USB-6009 multifunction DAQ. These devices are directly connected to the supervisory computer of the SCADA by USB. Each of them has 4 analogue inputs, 2 analogue outputs and 12 digital inputs-outputs. Analogue inputs are interconnected and electronically adopted for signal gathering of the voltage and current transducers. Analogue outputs are precise 12-bit voltage signals that are used for process control. By converting these signals thought analogue-pulse generators, the precise pulse signals are generated. First signal is used for control of the frequency converter (FC 1) of the “internal combustion engine”. The second signal enables pulse control of the frequency converter (FC 2) of the “brake”. Third signal is used for control of the traction motor by direct pulse-voltage regulation of the digital signal processing (DSP) board of the DC-AC converter.

This remote terminal unit also has function as distributed control unit (DCU). All this signal processing, data logging devices, sensor signal adaptation and control signal transformation is placed in one box set (Figure 5). This set is main control and regulation unit for HEV working stand. Therefore, it is named - HEV Remote Terminal Control Set (HEV-RTCS):

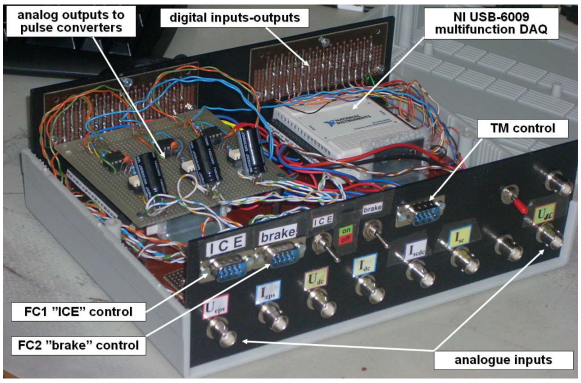

Fig. 5 HEV Remote Terminal Control Set (HEV-RTCS)

As main data acquisition and control device for SCADA realization is chosen the NI USB-6009 Multifunction DAQ. This device provides data acquisition functionality for applications such as data logging, portable measurements, and academic lab experiments]. This is flexible data acquisition tool, which can be connected to any PC by USB interface. It is powerful enough for more sophisticated measurement applications. This is USB data acquisition module and it is compatible with the following application software: LabVIEW, LabWindows/CVI, Measurement Studio and also compatible with programming languages like Visual Studio.NET, C/C++ and Visual Basic.

Main advantage of USB6009 is direct high-speed USB 2.0 communication with PC. As seen from the functional block diagram (Figure 6) USB microcontroller directly transduces data signals from analogue/digital inputs to USB interface. That enables easy access to the PCs central processor. That results with high-speed data transfer directly to central CPU of the PC without demanding significant processor power. This device also has integrated analogue-digital converters (ADC) for analogue inputs and digital-analogue converters (DAC) for analogue outputs.

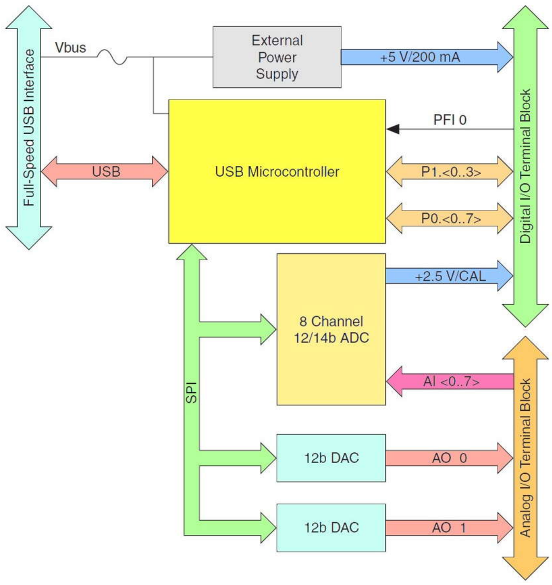

Fig. 6 NI USB-6009 functional block diagram

USB6009 doesn’t demands separate power supply. It is powered directly from USB port of the PC, which enables simplicity in connections and power supply independence. USB6009 offers stable power voltage sources, 5 [V] and 2.5 [V], with maximum current 200[mA] enabling direct relay and optocoupler connection.

By these means low-cost multifunction data-logger as is NI USB6009 is transformed in precise TTL pulse generator, which is much more impervious to EMI and can be used as control signal.

4. INTEGRATION OF HEV-RTCS ANALOGUE INPUTS IN HEV-SCADA

Each NI USB-6009 multifunction DAQ has four differential voltage analogue inputs (AI). They are independent among each other (without common ground), 14 bit, with maximum sample rate 48000 samples per second (48 kS/S). Range accuracy is 37.5 [mV] with measurement voltage range from -10 to 10 [V]. All eight inputs, from both USB6009, can be acquired and analyzed simultaneously. With LabVIEW software tool, each AI can be independently calibrated and adjusted.

These analogue inputs are for acquiring data from voltage and current transducers (Figure 7). On the working stand, in each power circuit, there are OMX305LEM current and OMX38DC voltage measuring devices.

As an input value OMX38DC transducers are measuring AC or DC voltage in range ±800[V]. Output signal is current proportional to the measured voltage (800[V]↔20[mA]). Two types of OMX305LEM current transducers are used. First is measuring AC or DC current with maximum value 50[A]. Output is current signal proportional to the measured current (50[A]↔50[mA]). Second type is with higher measuring range, up to 300 [A] and are used only in recuperative circuits I_{sc} and I_{scdc}. Output signal is proportional to the measured current (300[A]↔120[mA]).

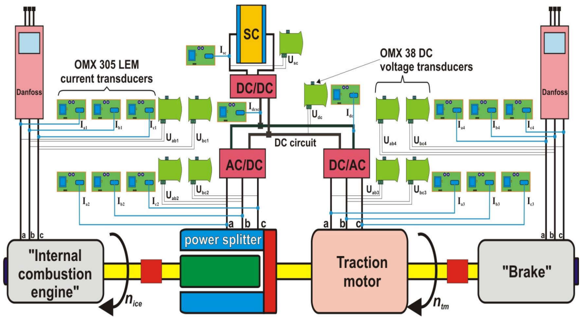

Fig. 7 Voltage and current transducers on the working stand

Current signal as output value in these sensing devices is advantage, because is impervious to the electromagnetic interference that can be generated from the surrounding devices. The accuracy of the measured value is not impaired from the length of transmission line. That enables data signals from the transducers to be transmitted without dependence of the placement and length directly to the data acquisition device, in this case to the HEV-RTCS.

Analogue inputs on USB6009 can measure voltage signal within range ±10[V]. Therefore, current data signal must be adopted with resistor shunts, which are placed within the HEV-RTCS. These shunts are R=220[Ω] and are in parallel connection to the AI (Figure 9).

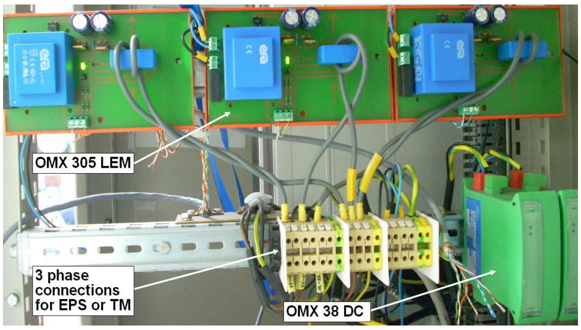

Fig. 8 Voltage OMX38DC and current OMX305LEM transducers

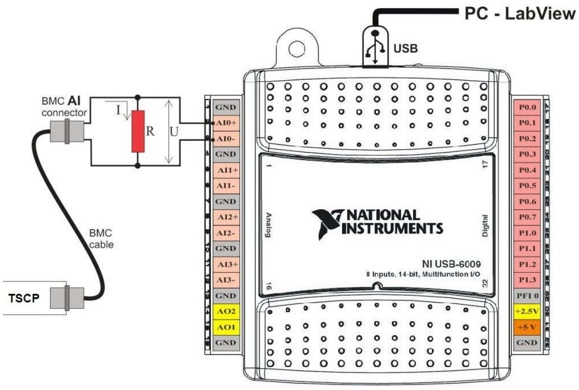

Fig. 9 Analogue inputs on NI USB6009 multifunction DAQ

High sampling attribute of USB6009 provides signal-form analysis. By using frequency extrapolation module for AC signals it is gained the output frequency f_{eps} from EPS voltage. Because EPS is synchronous machine, acquiring this data enables accurate real-time measurement of EPS relative revolutions, without measuring speeds of both shafts.

Alternating current signals are displayed and analysed in their real waveform as visualised on Front panel which is used as monitoring GUI (Figure 10). Output EPS voltage U_{eps} and current I_{eps} are oscillographically analysed with LabVIEW wave modules. These software features enable instant calculation of their effective values.

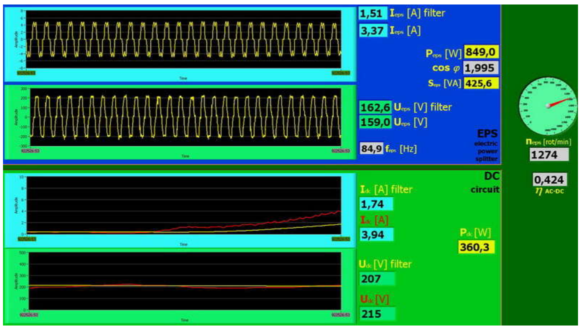

Fig. 10 Electrical quantities display panel of SCADA sistem

5. HEV-RTCS ANALOGUE OUTPUTS IN HEV-SCADA

USB6009 data-loggers are equipped with 2 analog outputs (AO) channels. Each is 12 bit voltage control channel with update rate 150[S/s] and range accuracy 7[mV]. AO regulates voltage from 0 to 5[V].

Three devices are regulated with HEV-RTCS. Besides that AO of USB6009 generates stable and precise voltage output, this signal can't be used for direct regulation of the remote devices. Voltage signal can be interfered from surrounding devices that generates electromagnetic interference (EMI). In order this signal to be impervious to the EMI it must be transformed in form that has this capability. As a solution for this problem, adaptation of this voltage signal is done by converting it to TTL square-wave pulse signal (Figure 10):

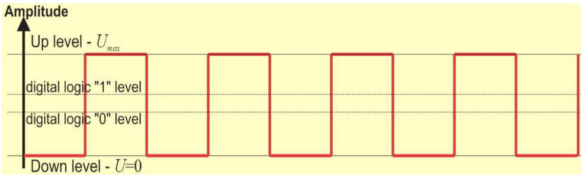

Fig. 10 TTL square-wave digital signal

For this purpose AD654 voltage to frequency signal converter has been used. That is monolithic V-f converter consisting of an input amplifier, a precision oscillator system and a high current output stage as shown on functional block diagram:

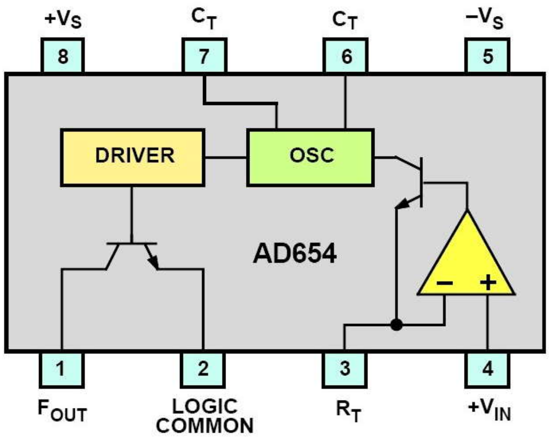

Fig. 11 AD654 functional block diagram

Schematic connection of AD654 to the AO of USB6009 is shown on Figure 12. Converter uses reference ground GND and reference voltage U_{daq}=5[V] from USB6009, which also presents power supply to the AD654. All the electronic components within HEV-RTCS are powered from USB6009 which provides stable voltage power source and it is supplied directly from PCs USB port.

By connecting RC circuit on the converter terminals (Figure 12) output pulse TTL signal with desired frequency can be generated (1).

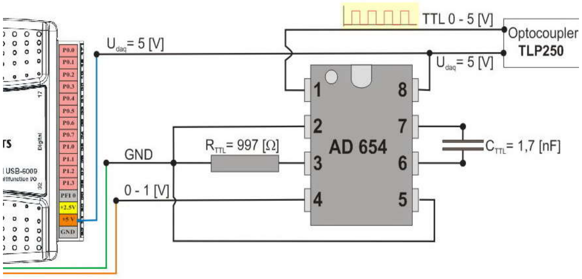

Fig. 12 Schematic connection of AD654 to the AO of USB6009, RC circuit and TTL pulse output to the TLP250 optocoupler

$$f(U_{AO}) = \frac{U_{AO}(t)}{10 \cdot R_{TTL} \cdot C_{TTL}} \quad (1)$$

For this purpose is needed TTL signal with frequency up to 65[kHz]. Therefore, resistor RTTL=997[Ω] and capacitor CTTL=1.7[nF] have been chosen. Voltage regulation of the USB6009 AO is in range from 0 to 1.1 [V]. By using equation (3-1) the output frequency is:

$$f(U_{daq\_\max}) = \frac{1{,}1}{10 \cdot 997 \cdot 1.7 \cdot 10^{-9}} = 64900[Hz]$$

$$\cong \quad f_{TTL\_\max} = 65[kHz] \quad (2)$$

This generated square-wave pulse signal must be adopted for voltage level that is suitable for the digital input pulse counter (DIPC) of the regulated device. Therefore, output TTL pulses from AD654 are connected to optocoupler type TLP250:

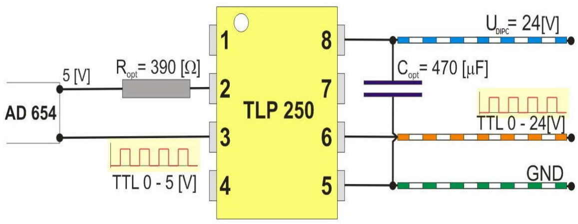

Fig. 13 Interconnection of the optocoupler TLP250

On the output side of the optocoupler is reference signal voltage (in this case UDIPC=24[V]) and reference ground GND from controlled device. Logical "1" of the output TTL signal has voltage U_{DIPC} and logical "0" has GND voltage (U_{GND}=0[V]). Frequency of this TTL signal is same as frequency of the generated signal from U-f converter AD654.

These pulses are received by DIPC of the regulated device, which reads their frequency (pulses per second). Voltage level of 24[V] and pulse frequency up to 65 [kHz] provides enough resistance from EMI. V-f converter AD654 and optocoupler TLP250 are soldered on one board for control of all three devices (Figure 14).

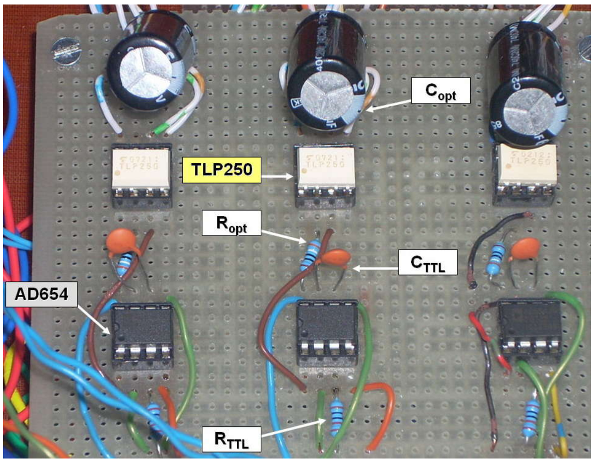

Fig. 14 V-f converter AD654 and TLP250 optocoupler within HEV-RTCS

By these means it has been created smooth and precise regulation of distant devices with analogue outputs of the Remote Terminal Control Set. Three devices are regulated and controlled: frequency converter (FC 1) of the “internal combustion engine”, frequency converter (FC 2) of the “brake” and DSP board of the DC-AC converter for traction motor of the hybrid-electric car system.

6. CONCLUSION

In this paper is presented solution for construction of control unit using low-cost data-logging devices. As a result creation of is highly - dynamic and control effective control set named as HEV-RTCS (HEV-remote terminal control set) that is used as main control and data acquisition unit for laboratory working set. The purpose of this control unit is acquisition of electrical quantities and real-time control of entire experimental stand.

This unit is a part of complex SCADA system of laboratory testing stand for new type of hybrid-electric car propulsion system. Its effectiveness has given significant results that enabled vast experimental data that provided significant results for development of this new technology.

7. REFERENCES

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