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Enhancing Urban Traffic Management through an Internet of Vehicles Framework

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ABSTRACT

In recent years, the large number of vehicles has led to a considerable increase in urban traffic. As a result, road traffic has become one of the major problems in most major cities. Road traffic problems are congestions and accidents resulting huge loss of time, damage to property and environmental pollution. These issues explain why many research programs around the world aim to improve our transportation systems; this is indeed a difficult task because the distributed, open, dynamic and partially controllable nature of transport networks makes it a complex area. This paper deals with the problem of managing and monitoring an intelligent transportation system, especially the urban traffic system, the aim of our contribution is limiting the nuisance caused by the increase in the use of transport. Thus, better mobility means limiting the environmental impact of the pollution generated, and improving safety and conditions of people's life. In this paper, we provide a short review on the impact of integrating the Internet of Vehicles into intelligent transportation systems. Furthermore, we propose a network architecture-based Internet of Vehicles to efficiently manage and monitor urban traffic systems. Our proposition is based on several technologies, selected carefully, such as wireless sensor network, RFID radio identification technology, Fog/Edge computing, and Cloud Computing. Overall, the proposed architecture improves the coordination and the communication among the road network entities, leading to advanced transportation systems.

1. INTRODUCTION

In our daily lives, technology becomes an important aspect, as it plays a major role in all domains and offers great benefits to individuals and societies. This involves the exponential growth of the concept of the Internet of Things, which is the interconnection of billions of different types of devices and sensors, called "smart objects", so that they cooperate to meet our needs with restricted capacities in terms of energy, memory, and processing powers [1].

Moreover, Transportation systems have a strong impact on the development of our society. Effective movement of goods and people contributes to economic growth and changes our territories through a good accessibility. That is why the development in transportation is one of important factors to indicate the well-being of a country [2]. In addition, the use of New Information Technologies and Communications to improve the transportation systems become a central solution in the field. The increase in computing power and the great development of the embedded systems, as well as the quality of sophisticated sensors, have made it possible to propose more effective control mechanisms; and better consideration of operators or users, the result is so-called Intelligent Transportation Systems (ITS).

Figure. 1 Intelligent Transportation System Model

However, the European report [3] on the evaluation of research programs in transport, Intelligent Transport Systems are considered vital for designing sustainable transport systems. According to this report, through the integration of information, communication and control technologies, ITS enable authorities, operators and individuals to make better decisions. ITS concern all systems that improve the use of means of transport using a set of technologies to meet the objectives of the domain.

Whatever the functionality associated with the ITS, it is built from data captured on the network, which is received and processed by software. As a result, all the advances in communications, sensors and computing are potentially benefiting the transportation systems. For example, the development of connected or autonomous vehicles is only possible through the implementation of communications between vehicles and with a suitable infrastructure, the deployment of high-performance sensors, and significant computing capabilities.

In addition, researchers of urban traffic systems have oriented their researches to the use of the Internet of Things' technologies, which led to the apparition of new concept: The Internet of Vehicles (IoV). IoVis based on the Internet, wireless sensor networks and sensing technologies to perform both intelligent recognition of road users (who are considered as objects), monitoring, and finally the management and the real-time treatment of road traffic.

To discuss the details of this topic, we have organized the rest of our paper as follows: In the next part, we provide a concise review of IoV, comparing it with VANETs, discussing its characteristics, and the different communication modes. After that, we propose an efficient IoV architecture, based on an IoV architecture, and we explain in detail its layers and its functioning.

Finally, we present the conclusion and the perspectives of this research work.

2. PROBLEM STATEMENT

The traffic flow in urban areas continues to be problematic and the number of fatalities and accidents on roadways remains high. It is assumed that the primary cause of road issues is human error. Therefore, it is necessary to reduce the amount of human involvement in the driving process. For that reason, automotive manufacturers have attempted to create car systems that assist drivers in safety and enhanced driving is necessary.

According to Ward's research, in 2010 they were more than 1 billion in operation worldwide, and total new vehicle sales suggest that there could be up to 2 billion vehicles by 2035.The traffic remains chaotic and the number of deaths and injuries on roadways remains high [4].

Moreover, more people live in urban areas than in rural areas, and cities are expected to continue growing. The United Nations estimates that in 2050 about 66 % of the world's population would live in urban areas. Such development has a significant influence on the quality of human daily life [5].

Governments over the world have applied a variety of countermeasures in order to reduce road traffic accidents, such as laws to regulate road traffic, or automotive systems to help drivers in the driving process. Despite the wide variety of countermeasures applied by governments over the world, the transportation system still needs improvements [5].

Connected Vehicles, Intelligent Transportation Systems (ITS) along with IoT technologies, constitute the concept of the Internet of Vehicles and have the potential to release efficient and more sustainable transportation systems that are becoming increasingly important to people's daily lives [6].

Figure. 2 Traffic congestion in big cities.

3. GENERAL NOTIONS

2.1 Internet of Things (IoT)

In [7], IoT was defined as a "dynamic global network infrastructure with self-configuring capabilities based on standards and interoperable communication protocols; physical and virtual 'things' in an IoT have identities and attributes and are capable of using intelligent interfaces and being integrated as an information network".

From the viewpoint of network, the IoT is a very complicated heterogeneous network, which includes the connection between various types of networks through various communication technologies [8].

In addition, the Oxford Dictionaries offers a concise definition of the IoT: Internet of things (noun): The interconnection via the Internet of computing devices embedded in everyday objects, enabling them to send and receive data [9]

Furthermore, the capabilities offered by the IoT can save people and organizations time and money as well as help improve decision-making and outcomes in a wide range of application areas.[10]

As well, IoT plays an important role in transportation field, such, vehicles have increasingly powerful sensing, networking, and data processing capabilities For instance, IoT technologies make it possible to track each vehicle' existing location, monitor its movement, and predict its future location. [8]

2.2 Internet Of vehicles (IoV)

It is a dynamic network, which consists of IoT enabled cars by using modern embedded and electronic devices like sensors and GPS, and integration of the information and communication systems to improve traffic flow, and to offer more effective road management and accident avoidance.

The urban traffic system has benefited from a lot of IoT applications like 'Internet of Vehicle' concept, Vehicle-to-Vehicle (V2V), and Vehicle to Infrastructure (V2I) communications, and have been transformed to a new level of interoperability, stability and efficiency, because, If vehicles communicate with each other, risks for accidents and mishaps would be very low. In addition, by using IoT technologies in the road traffic, we can monitor urban transportation systems, determine the state of traffic and pedestrian densities, identify damages and accidents, avoid collisions as needed, and optimize travel route [11].

4. IMPACTS OF TRAFFIC CONGESTION

Commonly, Traffic issues are a significant problem in urban areas, especially during rush hours [12]. According to [13] The United States spends over 836$ billion on crash-related costs, insurance premiums, and traffic law enforcement. In addition, traffic congestion costs Americans 124$ billion in direct and indirect losses, expected to reach 186$ billion by 2030. Therefore, traffic congestion in urban areas can affect Road Users' quality of traveling, society, and the economy [12].

- **Road users:** Traffic jams in urban roads can cause stress to vehicle users. In addition to the waste of time for motorists and passengers as well as their productive abilities. Furthermore, it can reduce the precision of calculating travel for each road user.
- **Society:**Traffic congestion may increase fuel consumption, and as a result, it can lead to air pollution. Unfortunately, in some cases, the congestion in urban areas can be considered a direct reason for road accidents. On another societal side, it can create late delivery of goods.
- **Economy:** Bottlenecks in urban roads, and according to the previous impacts, may provoke a reduction in employees' performances. Which can cause a decrease in economic growth, and will force the government to spend on enhancing the Intelligent Traffic Management Systems.

5. INTERNET OF VEHICLES AND VANETS

The use of communication technology and smart devices in vehicles has revolutionized the automotive industry. As a result, intelligent transportation systems have emerged with vehicles equipped with sensors and computers that may collect and process data for information exchange [14]. Vehicular ad hoc networks (VANETs) were introduced to enable direct communication between vehicles and infrastructure, but they face challenges such as unstable network services and limited handling of big data. In the era of 5G/B5G and the Internet of Things (IoT), VANETs are transforming into the Internet of Vehicles. Therefore, IoV aims to enhance safety, reduce congestion, and provide services through informationexchange between vehicles and relevant entities. Moreover, IoV encompasses various communication models and relieson vehicle networking and intelligence technologies. These advancements expand the communication scope and potentialof the IoV system [14].

5.1 Challenges in VANETS

The initial goals of VANET research technology were to ensure traffic safety [15], improve travel efficiency, and reduce pollutant emissions [16]. However, practical applications of VANET have faced challenges in commercialization. These challenges include the loss of network services when disconnected from other networks, incompatible network architectures, limitations in computing ability and storage space, and low accuracy of application services due to localized traffic data processing. To address these shortcomings, the emergence of the Internet of Vehicles offers promising prospects for the development of smart transportation systems. IoV overcomes the limitations of VANET through its heterogeneous network architecture, enabling cooperation with other communication networks. IoV is also compatible with most communication devices in daily life. The cooperation of different networks and the availability of multiple communication models (V2S, V2V, V2P, V2R, V2I) in IoV facilitate the sharing of big data, enhance the reliability of communication services, and expand the application scope of automotive communication. These advantages position IoV as a crucial development in the field [14].

5.2 Advantages of IoV

The Internet of Vehicles has attracted extensive attention from both academia and industry. It includes research areas such as intelligent transportation and telematics. The research focus of intelligent transportation is to improve travel efficiency and safety through projects such as the intelligent vehicle road system in the United States, the Eureka planin Europe, and the advanced dynamic traffic information system in Japan. The Internet of Vehicles combines mobile Internet, intelligent transportation systems, cloud computing, automotive electronics, and geographic information system tobecome a mixture of Internet of Things (IoT) and mobile Internet applications in the field of transportation [17]. In [13],authors have cited several advantages of the IoV, in particular, we highlight the following ones:

- IoV has transformed the road network entities into "new mobile devices". Ex: Vehicles, pedestrians, drones, etc.
- IoV creates networks that support functions such as intelligent traffic management.

- IoV consists of inter-vehicular, intra-vehicular, and vehicular mobile Internet components, enabling continuous connectivity and information exchange in vehicles.
- IoV facilitates the exchange of information between vehicles, road infrastructures, passengers, drivers, sensors, roadside units, and the Internet.
- IoV enables various services such as traffic management, road safety, healthcare apps, comfort, and infotainment.
- Communication protocols and standards like IEEE 802.11p, DMAC, VC-MAC, AODV [18], [19], DSR, and GPRS, among others, are used in IoV.
- IoV differs from Intelligent Transportation Systems by emphasizing information exchange among vehicles, humans, and road infrastructures.
- Estimated benefits per vehicle per year include savings on insurance rates, operation costs, and time spent in traffic for vehicle users.
- Society benefits from decreased accidents, traffic jam control, and reduced CO2 emissions.
- IoV has the potential to create around 400,000 new jobs in the United States.
- The global market size for IoV components is estimated to reach 115.26 billion Euros by 2020, according to the European Union.

6. CHARACTERISTICS OF IOV

Furthermore, the Internet of Vehicles environments illustrates a multitude of significant characteristics that contribute to their unique nature and functionality. In particular, we highlight the following key aspects [20]:

- **Dynamic topology and non-uniform node distribution:** The IoV network is composed of various entities. One prominent characteristic of this network is the mobility of vehicles, pedestrians, cyclists, drones, and mobile radars, which are constantly changing their locations, speed, and direction. Furthermore, the distribution of these entities in an IoV network depends on several factors, such as road conditions and driving habits [20]. This mobility aspect requires efficient communication and coordination mechanisms to ensure seamless connectivity and accurate data exchange, even in high-speed scenarios.
- **Heterogeneity:**IoV encompasses diverse vehicles with different types of communication technologies, such as DSRC, 4G/LTE, WiFi, and Zigbee... The heterogeneous nature of IoV enables compatibility and interoperability between different vehicles and infrastructures [20].
- **Granularity:** In the IoV, vehicles on the road can be categorized into subsets called Sub-IoVs, which operate at a more localized level and have lower granularities. By using different granularities, the IoV enables flexible and scalable data collection and analysis for intelligent transportation systems [20].
- **Scalability:** The IoV network is massive, with a large number of vehicles and infrastructure; therefore, IoVshould be scalable rapidly, to handle the growing volume of data, the number of connected devices, and the complexity of IoV applications [20].
- **Big data and high processing capability:** In IoV networks, vehicles, sensors, road infrastructure, drivers, pedestrians, and all other entities continuously generate huge amounts of data. Therefore, it should be collected, aggregated, processed, and analyzed in real-time to make decisions and extract valuable insights for improving transportation efficiency [21]. Furthermore, data processing and decision-making are assured by the fog/edge servers for rapid responses and by the cloud servers for general and large-scale decisions.

6.2 Communication modes in IoV

The Internet of Vehicles is a considerable shift in vehicle networking, leading to the development of intelligent transportation systems. IoV is a heterogeneous network consisting of various communication modes illustrated in Figure 3:

- **Vehicle-to-Vehicle (V2V):**inter-vehicle communication allows vehicles on the road to exchange information, messages, and even sensor data. Such communication not only ensures road safety but also enables cooperative driving by sharing details like location, speed, acceleration, and destination of each vehicle.
- **Vehicle-to-Person (V2P):** it enables vehicles to communicate with drivers, pedestrians, cyclists, and traffic police personnel, providing them with important information to enhance safety and improve overall traffic management.
- **Vehicle-to-Roadside (V2R):** the exchange of information or messages between vehicles and roadside units, like traffic lights, road signs, toll booths, parking systems, cameras, and radars.
- **Vehicle-to-Infrastructure (V2I):** it represents the communication between vehicles and the infrastructure responsible for high processing capabilities via WiFi or cellular networks like LTE/4G/5G [14].
- **Vehicle-to-Sensors (V2S):** this communication enables vehicles to interact with various types of sensors locatedon both sides of the road such as radar sensors, Inductive Loop Detectors, Ultrasonic sensors, microwave sensors, infrared sensors, and acoustic sensors [22].

6.3 IoV application in transportation systems

The Internet of Vehicles has attracted widespread attention in the market and has applications in different fields of transportation, which can be divided into the following categories [20], [21], [23]:

- **Healthcare applications:** The main objective of this type of IoV application is to decrease road accidents, and as a consequence, road deaths, for instance: Intersection collision warning [21]. In addition to real-time communication between vehicles and healthcare professionals. In emergencies, vehicles equipped with medical devices can establish a connection with doctors or specialists who can remotely provide guidance and instructions for immediate medical intervention. In addition, Vehicles can be equipped with sensors and wearable devices to monitor the health parameters of passengers or drivers.

- **Safety-related application:**Vehicles diagnostics and maintenance [21], hazardous location notification, and collision warning systems were designed to minimize the number of accidents in IoV networks.
- **Traffic efficiency application:** it offers enhanced route guidance and navigation, to improve road traffic managementand advance the field of traffic routing, like in a previous research work [22].
- **Comfort-related applications:** smart parking systems [24]and energy supply stations.

7. METHODOLOGY

7.1 IoT Architectures' Background

In [25], authors surveyed existing IoT architectures, which are three-layer architecture, Middleware-based architecture, Service Oriented Architecture (SOA), and Five-layer architecture. Furthermore, they marked that the five-layer architecture is the most appropriate model for IoT applications, due to its simplicity, by the way, this later consists of five layers : 1. Objects layer or perception layer, which contains physical components like sensors, actuators, 2. Objects Abstraction layer, by using this layer we transfer data generated by Objects layer over WiFi, GSM... 3. Service management layer, which processes data, makes decisions, and delivers services over network protocols. 4. Application layer, that provides high quality smart services to meet customer's needs, and 5. The Business layer that supports decision-making based on big-data analysis.

Authors of [26] presented two types of IoT architectures; the basic Three-layer architecture, it consists of perception or sensor layer, Network layer and application layer, and the four-layer SoA-based IoT architecture, which is composed of Perception layer, Network layer, Service layer, and Application layer, service layer is made of service discovery, service composition, service management, and interfaces. According to the authors, the service-oriented architecture is more flexible and generic, because a service layer is developed between network layer and application layer to provide the data services in IoT architectures like data aggregation and processing in network layer, and data mining, data analytics in application layer. After that, they introduced the relevant enabling technologies and challenges of each layer, and they token the four-layer SoA-based IoT architecture as an example.

In [27], authors proposed a four-layer architecture for future heterogeneous IoT, which contains Sensing layer, Networking layer, Cloud computing, and Application layer, we explain each layer with more details in the next part of the paper.

7.2 The proposed IoV architecture

In [27], the authors propose a four-layer architecture for the future Internet of Things; we combine this architecture with the concept of fog/edge computing, and we add a novel layer to this architecture, which is the edge servers' layer. Then, we adapt this architecture to be destined for road traffic systems; in this section, we explain our architecture in more detail.

Layers of the proposed architecture

First, we present the layers of our architecture illustrated in Figure 3:

- Sensing layer: This layer represents the physical sensors, actuators, and RFID tags that aim to capture, collect, and transmit information [25]. A large number of sensors are deployed in the monitoring area [27], which is in our case the urban road; we use sensors to collect data about the state of the road (if it is congested, or there is an accident or a fire in the road). From vehicles that are equipped with RFID tags, and pedestrians who have all smart phones in their possession, or swatches connected to the internet. Those sensors send the captured data to the sink node, which we call the master node; we will explain its role in the Fog/Edge computing layer.

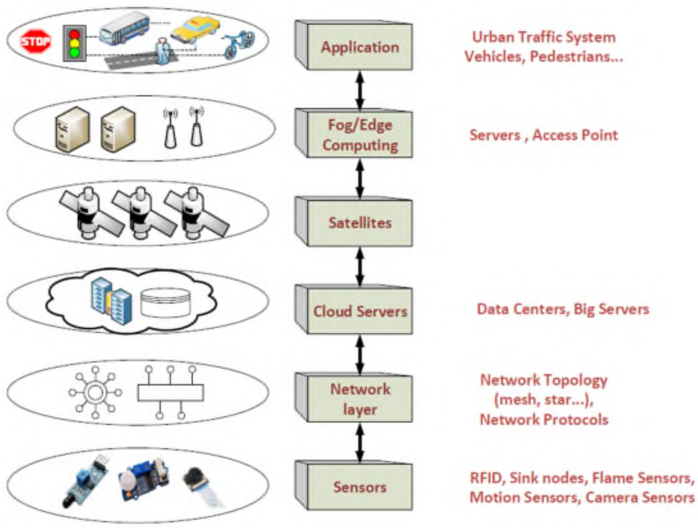

Figure. 3: The proposed architecture's layers.

- Network layer: In this layer, we implement network protocols, and the corresponding topologies like star topology, tree topology, mesh topology, or hybrid topology, in order to forward data packets from source node to destination node [27]. However, we consider self-organizing network protocols, because we need more robustness and efficiency in the construction of network topology, like the IPv6 routing protocol "RPL", which is a distance vector routing protocol designed by the Internet Engineering Task Force IETF, for Low Power and Lossy Networks.
- Cloud layer: This layer is very important to handle thetremendous amount of data collected, and transmitted byother layers to cloud servers and big

data centers, tobe processed, stored, and to make decisions based ondata analysis [27], [26], thanks to the powerful analyticalcomputing capacities that have cloud servers. Cloudcomputing is now a mature technology used to create,store, and use data over the Internet. Although, when amassive amount of data need to be stored, processed, andanalyzed efficiently in data centers and cloud servers,a new technology appears to fulfill the gap, which isFog/Edge computing, to extend cloud computing to becloser to the network of things [26].

- Satellite Sub-layer: To transmit data between Edge Servers and Cloud data centers and servers, we useSatellites, to gain time, throughput, and energy.
- Fog/Edge Computing layer: In this layer, we have two types of devices, the Master Nodes, and the Edge servers.We can use Edge servers for insuring processing, andstorage and making decisions near the network, insteadof doing all the computations in the cloud servers, hence,Edge computing has faster response and greater qualitythan cloud computing [26], especially, when we are facedto a real-time application like road traffic.We update datacenters of the cloud once a day, at night, to minimizedisruptions during peak hours, ensure that resources areavailable at night when fewer users are active, andreduce competition for bandwidth; on the other hand, wetransmit data from master nodes to Edge Servers severaltimes and periodically in the journey, because we canplace some types of data for further computations andanalysis, however, the high priority data, we address immediately to the closest Edge server, to ensure thereal-time property of the road traffic system. The masternode is an access point with good processing, energy,and transmission capacities, if we compare it with theroad sensors, its role is to 1- receive the data collectedby all the sensors near it, i.e. In the same area. 2- Afterthat, it makes some calculations and data aggregations to reduce the big amount of the collected data, becauseand without a doubt, we will find a lot of redundancy,because, the sensors are in the same region and they willcapture sometimes the same information.
- Application layer: The application layer responds tousers' needs, by providing them the corresponding services[25], for instance, a car driver needs to know if thisroad is congested or not, he uses our application to get thebest response. Our application here is urban road trafficmanagement, which includes vehicles, pedestrians withtheir smartphones, or smart watches, road sensors, andother smart devices that are connected as objects in thenetwork, delivered data is used to ensure the real-timemanagement of the urban road traffic. Edge and cloudservers can manage and monitor remotely objects basedon data analytics and visualization [27].

7.3 The functioning of the proposed architecture

Our Architecture is hybrid, in terms of connecting objects inthe IoT network, which means that objects cooperate with eachother and exchange information on traffic; and hierarchical,because objects connect with the master node to transfer thedata captured by sensors to the Edge Servers, in addition, dataprocessing in edge servers will be sent for processing andmake decisions to the cloud centers, as it's illustrated in Figure 4.

In each vehicle, we find a GPS (Global Positioning System); this later is responsible for receiving important data like location, time, and weather conditions from satellites [2]. In addition, we have RFID chips; their role is to exchange information with other vehicles and pedestrians and with road sensors using Zigbee IEEE 802.15.4. Road sensors are responsible for capturing road traffic data, from vehicles and pedestrians, these data tell us if there are congestions, accidents, or flames. . .

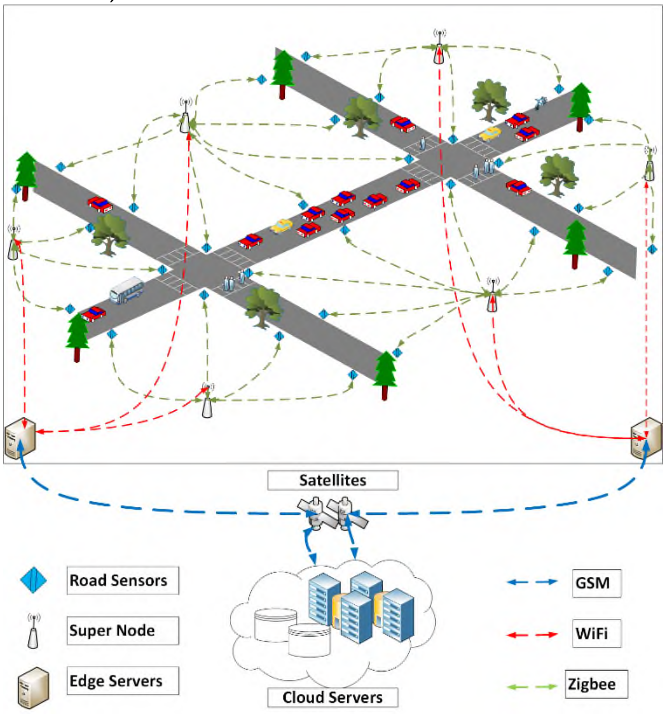

Figure.4: The proposed architecture of the ITS-based IoV

After that, they transmit the collectingdata to the master node via WiFi IEEE 802.11. The masternode consists of communication and data treatment modules;the communication part is a wireless antenna, which is responsiblefor receiving and decoding the transmitted data packetsfrom the road sensors or the edge servers. Furthermore, thedata treatment module is used to do some data aggregationon the data received from the road sensors, because therewill be certainly redundancies, in addition, mechanisms ofdata aggregation aim to reduce the amount of transmissiondata and energy consumption [2]. The aggregated data areforwarded to the nearest edge server via GPRS (General PacketRadio Service), which is a cellular communication protocol,named 2.5 Generation (2.5 G), it means that is between thesecond generation and the third generation of GSM (GlobalSystem for Mobile communication). Each Edge Server makeprocessing and calculations on data transmitted from Masternodes, make decisions, and preventions, to raise alarm todrivers or pedestrians to avert them if there is congestion,accidents,

and flames. . . to avoid more damage on the road;this process is repeating during all day long. Edge servershave a big power of storage and processing to make betterdecisions to ameliorate the quality of transportation in urbanareas, they are an intermediary between Cloud servers anddata centers, and sensor networks on the road. Processed data,decision-making, and preventions will be sent to Cloud serversthrough satellites, we use 4G to transfer data. Why use theseexisting protocols? We use any available network within therange, to insuring communication between components in an
IoT system, which seems to be a better solution [2]. Like here
in our case, we use WiFi, and cellular networks like GPRSand 4G LTE, which are pre-existing network architectures,in order to avoid implementing new infrastructures. In Cloudcenters, we make global and heavy operations, due to the bigcapacity of processing and storage, we use virtualization anddata analytics to make better decisions and preventions andstore data to use for improving the urban road traffic system.

CONCLUSIONS

The Internet of Vehicles is an important concept in the field of transportation and autonomous driving. It connects people, vehicles, and road infrastructure. It has gained commercial and economic interest and attracted the attention of researchers in the transportation area due to advancements in computation and communication technologies. This paper provides a short review of the impact of IoV on intelligent transportation systems by discussing problems and major issues in road systems, and the challenges in VANETS. After that, we present the key aspects of the IoV ecosystems: the most importantcharacteristics, advantages, and modes of communicationandthe applications of IoV in transportation systems. Then, wepresent the IoV-based architecture. Therefore, the proposedarchitectureis generic and flexible for all urban traffic systemsand can be applicable in the real world, because we bringtogether current and existing IoV and IoT technologies. Theproposed architecture is global; we work to detail it more and more, using IoT and IoV technologies, and to implement its layers in the near future; once successfully implemented, the reduction of damages, collisions, congestion, and pollution in the urban road traffic will certainly benefit the quality ofpeople's lives in urban areas.

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Optimal Placement and Sizing of Energy Storage Systems in Smart Grids

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ABSTRACT

In recent years, numerous incidents of voltage instability have occurred in smart power grids. The primary factor contributing to this instability is the reactive power limit of the system. Flexible Alternating Current Transmission Systems (FACTS) devices can play a pivotal role in mitigating voltage instability. One such FACTS device is the Static Var Compensator (SVC), which offers significant and continuous voltage control across various operational conditionsIn this context, this paper introduces a novel algorithm designed to determine the optimal placement and sizing of Static Var Compensators, aiming to enhance the voltage security of power systems during substantial disturbances. The selection of the most suitable location and appropriate size for the SVC is based on the sensitivity of the voltage magnitude, specifically dV/dQTo validate the effectiveness of this approach, simulations were conducted using a model of an IEEE 9-bus power network. The purpose was to showcase the positive outcomes resulting from well-implemented SVCs.

1. INTRODUCTION

The power system is undergoing a transformation towards a more decentralized and intelligent power grid. This transition involves increased adoption of distributed generation and active participation of end-users. It is widely recognized that the demand for flexibility is growing. Even conventional power generation methods, which have been in use for decades, are grappling with rising power consumption demands. As a consequence, stability is diminishing, particularly in terms of reactive power within the system.

In this context, the concept of flexibility has been defined diversely. One such definition characterizes it as the alteration of generation injection and/or consumption patterns, either at an individual or collective level. This modification is often triggered by external signals and aims to serve the energy system or uphold stable grid operations [1]. In scenarios where voltage limits need to be maintained, reactive power is injected locally. However, unlike active power, reactive power cannot be transmitted over long distances, necessitating its local provision through various means [2].

Therefore, Flexible Alternating Current Transmission System (FACTS) controllers emerge as a fitting solution to supply reactive power locally. While generators possess reactive power control capabilities, the location of reactive power demand can significantly limit their effectiveness. Given the substantial costs associated with FACTS devices, their optimal placement within the system is crucial. The impacts of Thyristor-Controlled Series Capacitors (TCSC) and Static Var Compensators (SVC) on system load curtailments are studied by placing these devices within the system using a trial-and-error approach. However, relying on a trial-and-error methodology lacks a rigorous mathematical foundation for determining the best location of these controllers. As these devices involve considerable expenses, a more systematic mathematical method is proposed in this study. SVC is chosen for this purpose due to its cost-effectiveness.

This work demonstrates how the application of FACTS technologies, such as SVC, serves as an effective solution for addressing instability issues. It helps prevent voltage collapse and enhances the overall stability of the power system.

2. STATIC VAR COMPENSATOR

The establishment of a Smart Grid necessitates advanced technologies to optimize its functionality and intelligence. The term "Smart Grid" should be perceived as an opportunity to enhance power system performance and elevate operational capabilities. Among the devices contributing to this enhancement are Flexible Alternating Current Transmission System (FACTS) devices, with the Static Var Compensator (SVC) standing out as a significant technology for power system compensation. SVC operates as a control device, offering rapid response times that outpace traditional mechanically switched reactors or capacitors.

2.1 System Modeling

SVC serves as a shunt-connected variable generator or absorber. Its output is adjusted to exchange capacitive or inductive current, which in turn maintains or controls specific parameters of the electric power system, often focusing on bus voltage regulation. This device incorporates distinct components for generating leading and lagging Vars [3].

Within the active control range, the susceptance (Bsvc) and the associated reactive current can be adjusted based on the voltage regulation slope characteristics illustrated in Figure 1. The specific slope value hinges on factors such as desired voltage regulation, allocation of reactive power among different sources, and additional system requirements. Typically, this slope value ranges from 1% to 5%. The behavior of the SVC is akin to a shunt capacitor set to its maximum value (BCsvc) when operating at the capacitive limit. Conversely, it functions as a fixed shunt reactor at the minimum value (-BLsvc) when approaching the inductive limit. These limits become relevant during substantial fluctuations in bus voltage. The inductive limit becomes applicable as the bus voltage surpasses the upper threshold, while the capacitive limit comes into play when the voltage falls below the lower limit [4].

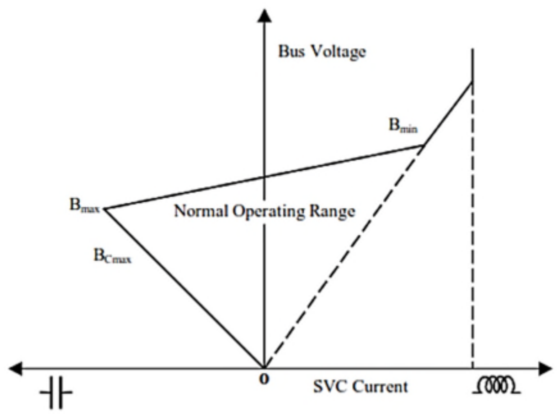

Figure. 1SVC output characteristics.

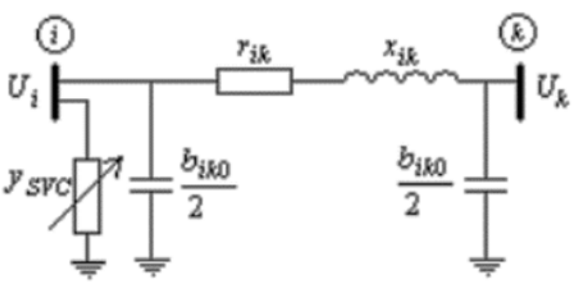

Figure. 2 Equivalent circuit of an SVC connected to a bus terminal.

Generally, the shunt connected SVC can be represented by its shunt current injection model. The current injection (ISVC) into the bus, where the SVC is connected, can be written as

$$\underline{I_{svc}} = jB_{svc}V \quad (1)$$

$$B_{svc} = B_c - B_{TCR} = \frac{1}{X_c X_l}\left\{X_l - \frac{X_c}{\pi}[2(\pi-\alpha)+\sin 2\alpha]\right\},$$

$$X_L = \omega L, X_c = \frac{1}{\omega C}, \quad (2)$$

Where, BSVC, α, XL, XCare the shunt susceptance, firing angle, inductive reactance, and capacitive reactance of the SVC, respectively. $\omega = 2\pi f$, where f is the frequency of the supply.

The reactive power injected into the bus due to SVC can be expressed as:

$$Q_{svc} = B_{svc}V^2 \quad (3)$$

Where V is the voltage magnitude of the bus at which the SVC is connected.

The SVC can be modeled by a shunt variable admittance and can be placed either at the terminal bus of a transmission line or in the middle of a long line [5]. Considering the SVC without losses, the admittance only has its imaginary component and it can take values in a specified range (usually between 0 and the maximum SVC capacity studied). This is denoted by:

$$y_{SVC} = jbSVC \quad (4)$$

This part considers the case of an SVC installed in a node Fig.3 with a continuously variable set point [6].

In this case, only one term of the nodal admittances matrix is modified, corresponding to the node where the SVC is connected:

$$Y_{ii}' = Y_{ii} + y_{svc} \quad (5)$$

The matrix is therefore modified as follows:

$$[\underline{Y}'_{nn}] = \begin{pmatrix} \underline{y}_{ik} + \frac{\underline{y}_{ik0}}{2} + \underline{y}_{SVC} & -\underline{y}_{ik} \\ -\underline{y}_{ik} & \underline{y}_{ik} + \frac{\underline{y}_{ik0}}{2} \end{pmatrix} \quad (6)$$

3. PROBLEM FORMULATION

Consider a transmission network represented by its nodal admittance matrix [Ynn] and the vector of nodal powers [S].Let Sv be the vector of state variables (voltage phase and magnitude) and let Cv be the set of control variables (location, size, reference SVC values, the domain of variable location – consisting in a set of nodes where the SVC placement study is carried out).

The problem lays in determining Sv and Cv to minimize or maximize a certain objective function f (Sv, Cv) while verifying the following two types of constraints:

g(Sv,Cv) = 0 (Kirchhoff's law)

h(Sv,Cv)≤0 (security constraints) (7)

The domains of definition for the variables are also set as inequality constraints.

The objective function when searching for optimal SVC locations can include several optimization criteria. This work proposes a multi-objective function, searching for a solution consisting of both the SVC location and SVC size that minimizes the voltage deviations, active power losses, and installation costs.

The objective function consists of three objectives, two of which are technical and one economical, as follows:

A.Minimize the active power losses:

$$O_1 = \sum_{l=1}^{b} R_l I_l^2 = \sum_{l=1}^{b} \left[V_i^2 + V_j^2 - 2V_iV_j\cos(\delta_i - \delta_j)\right] Y_{ij}\cos\varphi_{ij} \quad (8)$$

where b is the number of branches, R1 is the resistance of line l, I1 is the current through line l, Vi i are the voltage magnitude and angle from node i and Yij , φijare the magnitude and angle of the i-j line admittance

B. Minimize the voltage deviations

$$O_2 = \sum_{i=1}^{n} \left(\frac{U_{iref} - U_i}{U_{iref}}\right)^2 \quad (9)$$

Where n is the number of buses, Uirefis the reference voltage at bus i and Ui is the actual voltage at bus i.

Operational constraints

Power flow balance equations. The balance of active and reactive powers must be satisfied in each node:

$$P_{Gi} - P_{Li} = U_i \sum_{k=1}^{n} \left[U_k[G'_{ik}\cos(\theta_i - \theta_k) + B'_{ik}\sin(\theta_i - \theta_k)]\right]$$

$$Q_{Gi} - Q_{Li} = U_i \sum_{k=1}^{n} \left[U_k[G'_{ik}\sin(\theta_i - \theta_k) + G'_{ik}\sin(\theta_i - \theta_k)]\right] \quad (10)$$

where the conductance G'ik and susceptance B'ik represent the real and imaginary components of element Y'ik of the [Y'nn] matrix, obtained by modifying the initial nodal admittance matrix when introducing the SVC.

Power flow limits.

The apparent power that is transmitted through a branch I must not exceed a limit value, Slmax, which represents the thermal limit of the line or transformer in steady-state operation:

$$S_l \leq S_{lmax} \quad (11)$$

Bus voltages.

For several reasons (stability, power, and quality, etc.), the bus voltages must be maintained around the nominal value:

$$V_{imin} \leq V_{inom} \leq V_{imax} \quad (12)$$

In practice, the accepted deviations can reach up to 10% of the nominal values.

SVC reference value

The size of an SVC is expressed as an amount of reactive power connected to a bus of voltage 1p.u. Sign conventions: a positive value indicates the fact that the SVC generates reactive power and injects it into the network through the node to which it is connected (capacitive state); a negative value characterizes the inductive state, where the SVC absorbs reactive power from the network.

The SVC size is a variable that can take nv discrete values from the interval:

$$\text{QLmax} < Qsvc < Qcmax \quad (13)$$

The SVC in our case will be modeled as a reactive power generator connected to a bus in a system .

The reactive power generated by SVC is given by:

$$Q_{SVC}^{Min} \leq Q_{SVC} \leq Q_{SVC}^{Max} \quad (14)$$

If the SVC is operating outside the limits, so the bus becomes PQ-type and the reactive power Q is set and is expressed by

$$Q = -B * V^2 \quad (15)$$

Where

B: equivalent susceptance of the SVC

V: the calculated voltage magnitude at the SVC node.

4. PROPOSED ALGORITHM

In this work, the main objective is to find the optimal location and determine the size of the SVC for enhancing voltage security during emergency operating conditions.

This can be achieved through minimizing the sensitivity of voltage magnitude (dV/dQ) under severe line contingencies. The objective function is given by:

$$F_1 = \text{Minimize}[F] \quad (16)$$

The term F represents the dynamic voltage deviation (dV/dQ) at each node. The minimum value of the sensitivity of voltage magnitude (dV/dQ) is used to find the best location of SVC. Dynamic voltage deviation is calculated as follows:

$$F = \sum_{k=1}^{N_{PQ}} \frac{(Vi - Vup)}{(Q - Q0)} \quad (17)$$

Where:Vi is the voltage magnitude at node i.

Vup is the upper limit of the voltage at node i.

Vlow is the lower limit of the voltage at node i.

The equality and inequality constraints are:

-Load Flow:

$$Q_{Gi} - Q_{Di} - \sum_{j=1}^{N} V_iV_{ij}Y_{ij}\sin(\delta_{ij} + \gamma_j - \gamma_i) = 0 \quad (18)$$

$$P_{Gi} - P_{Di} - \sum_{j=1}^{N} V_iV_{ij}Y_{ij}\cos(\delta_{ij} + \gamma_j - \gamma_i) = 0 \quad (19)$$

-Reactive Power of SVCs:

$$Q_i^{min} \leq Q_i \leq Q_i^{max} \quad (20)$$

Where Qi is reactive power injection at node i by SVC;

-Voltage

$$V_i^{min} \leq V_i \leq V_i^{max}; i \in N_{Node} \quad (21)$$

Where Vimin and Vimax are minimum and maximum voltage at node i respectively.

Optimal placements of SVC controllers

The proposed algorithm for finding the optimal placement of SVC controllers involves the following steps:

- Create several critical contingencies such as line outage or generator outage. Then, load flow computation is done, and voltage magnitudes of several 220 kV nodes are computed for each contingency.

-Once the voltage magnitudes enter the specified dynamic limits (Vlower < Vi < Vupper), the voltage sensitivity dv/dq is computed for each contingency.

-The process is continued until the voltage magnitudes are less than the lower limit of the voltage at node i Then, nodes are ranked according to the dv/dq values.

The flowchart of the proposed algorithm is shown in Figure 3.

This paper proposes a new algorithm to find the optimal location and size of SVC controllers in order to increase the voltage security of power systems during large disturbances. The optimal location and size of SVC are determined based on the voltage magnitude sensitivity factor.

5. SIMULATION RESULTS AND DISCUSSION

For the testing and evaluation of the proposed algorithm, the test set up system IEEE 9 bus model is considered. The IEEE 9 bus system that is illustrated in Figure 4 consists of 3 generating units and 9 buses out of which one is the swing bus [7]. Four cases are studied taking into consideration the load bus voltages profiles for each case.

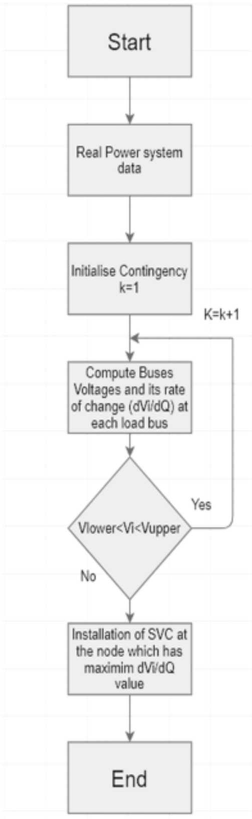

Figure. 3 Flowchart of the proposed algorithm.

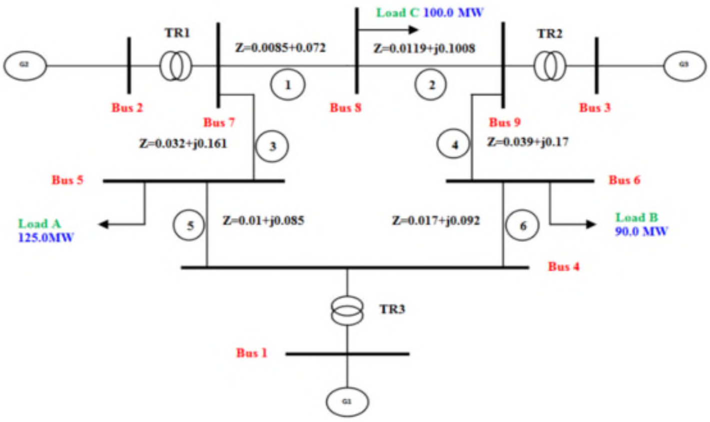

Figure. 4 IEEE 9 Bus Power Network Model.

The PSS®E software has been used for simulating the dynamic of the disturbance and presenting the frequency generators and load bus voltages plots before and after the implementation of the load shedding scheme. After simulatingthe proposed algorithm using PSS®E software, Matlab has been used to determine the main parameters of the algorithm which are the bus where the maximum value of dV/dQ can be obtained and the size of SVC. The simulation is done by considering the following cases.

Scenario 1: Loss of Transmission Line 3

The case study 1 of the IEEE 9 bus system considers the loss of transmission line 3 connecting bus 5 to bus 7. The resulting load bus voltages waveforms obtained from PSSE during the disturbance without installing SVC are shown in the figure 5.

The most critical lines of the IEEE 9 bus model are the lines that are connecting the generator buses to the remaining buses of the system. If a generator has only one transmission line connecting to the power system, this becomes a crucial line as its loss can result in the isolation of the generator from the whole system which is equivalent to the studies that will be carried out in the next case studies.

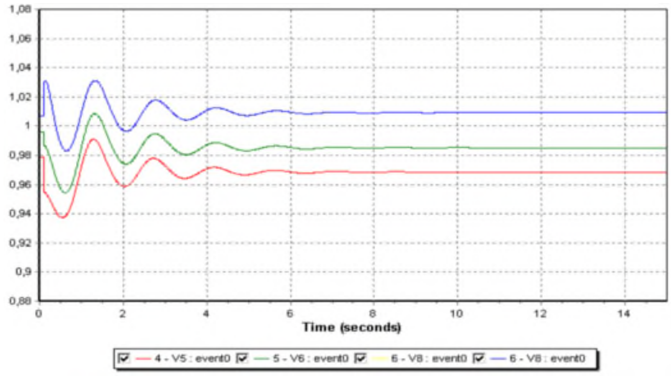

Figure. 5 Case **1** : Load Bus voltages (without SVC).

In this case, tripping the line 3 is not really crucial since we still have line 1 that is connecting generator 2 to the power system. As a result, the load bus voltages are not really affected much by this disturbance. This latter is considered as a very small disturbance that does not require any compensation. However, the recovery of the very small decline of the system load bus voltages is done by the spinning reserve.

Scenario 2: Outage of Generator 3

The case study 2 that we considered for the IEEE 9 bus model is the loss of generator 3. This causes the load bus voltages to be reduced after the disturbance takes place and before installing any SVC, the load bus voltages behaviors are shown in the figure 6.

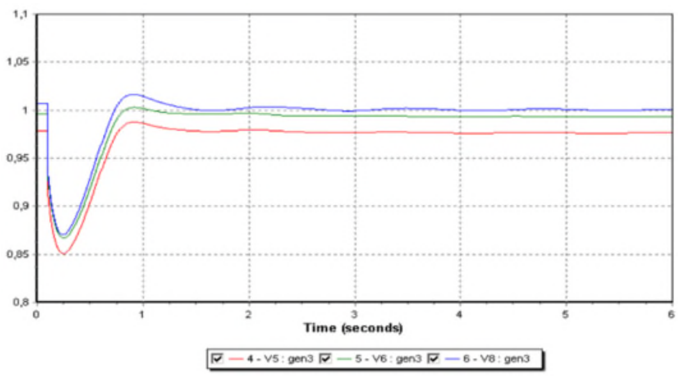

Figure. 6 Case 2: Load Bus Voltages before installing SVC

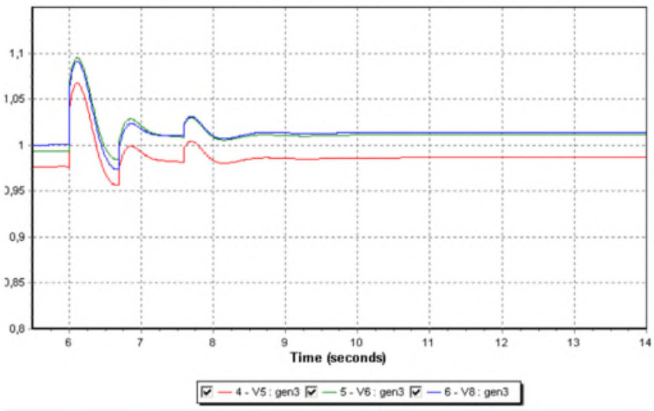

Figure. 7 Case 2: Load Bus Voltages after installing SVC

Figure 6 represents the load bus voltages before installing SVC. These voltages decrease below the rated value and they become stable at the following values:

-Voltage at load Bus 5: 0.976 p.u,

-Voltage at load Bus 6: 0.99 p.u,

-Voltage at load Bus 8: 1.00 p.u

Now, the voltage sensitivities for each load bus under this case are given in table 1.

Table I Voltage Sensitivities at each Load Bus (Case Study 2)

Load bus Number	dV/dQ
5	0.000103188
6	0.000479844
8	0.000193001

The maximum value of dV/dQ value is 0.000479844 at bus 6.It can be noticed that the SVC with a range between 100 Mvar and 200 Mvar to be installed at any load bus gives good results. The load bus voltages experience a gradual improvement. This can be noticed in Fig.7.

Scenario 3: Outage of Generator 3 with increase of load A & C by 50 %

The third case study of the IEEE 9 bus system considers the loss of a generator at bus 3 with an increase of load A & C by 50 %. This loss caused a reduction in the total generated power of the system by 196.6885 MW. The load bus voltages are also affected by the loss in the generated power. This can be seen in the plots of the load bus voltages in figure 8.

Before installing SVC, the load bus voltages decrease below their predetermined standards and become stable at the following lower values: -Voltage at load Bus 5: 0.95477 p.u,

-Voltage at load Bus 6: 0.97328 p.u, - Voltage at load Bus 8: 0.98175 p.u.

The voltage sensitivities; dV/dQ values are calculated individually for each load bus and the results are listed in table 2.

Table II Voltage Sensitivities at each Load Bus (Case Study 3)

Load bus number	dV/dQ
5	0.000926756
6	0.000103185
8	0.000850300

The maximum value of the dV/dQ is 0.000926756. The SVC with a range between 100 Mvar and 200 Mvar to be installed at each load bus is obtained using the voltage sensitivity with maximum value according to the proposed algorithm. It can be noticed that the best results can be obtained when the SVC of 130 Mvar is installed at bus 5. The load bus voltages experience a gradual improvement. This can be noticed in Fig.9.

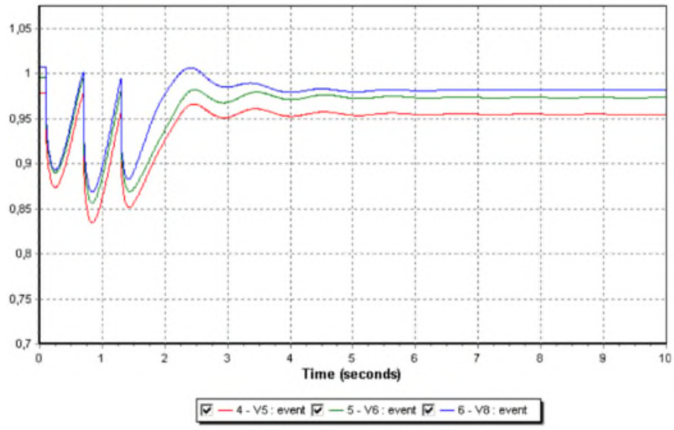

Figure. 8 Case 3: Load Bus Voltages before SVC installation.

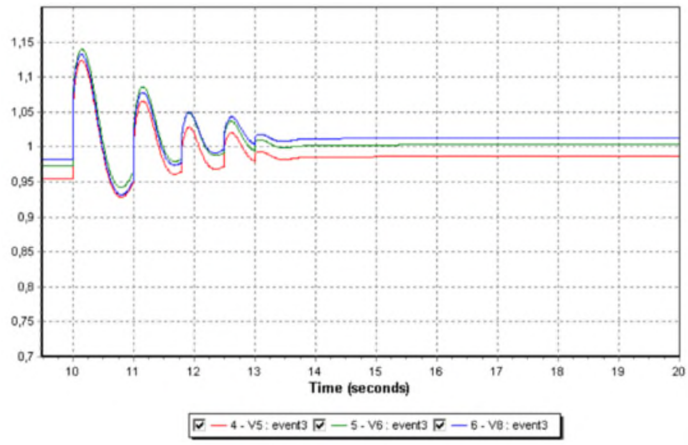

Figure. 9 Case 3: Load Bus Voltages after SVC installation.

Scenario 4: Increase of Load A, B & C by 100 % (Overload)

The last case study of the IEEE 9 bus system is the overload that consists in an increase of load A, B & C by 100 %. The generation power loss due to this overload is 314.6885 MW. The load bus voltages plots after the disturbance and before installing SVC are illustrated in Figures 10 and 11.

The load bus voltages are also changed due to the loss of some of the generated power. As it can be seen in the figure above. The load bus voltages are definitely lower than the acceptable values such as: -Voltage at load Bus 5: 0.924 p.u, -Voltage at load Bus 6: 0.926 p.u, and -Voltage at load Bus 8: 0.9761 p.u.

Table IV Voltage Sensitivities at each Load Bus (Case Study 4)

Load bus number	dV/dQ
5	0.001194300
6	0.000859908
8	0.000955450

The voltage sensitivities for this case are calculated and tabulated in table 3.The maximum value of the dV/dQ is 0.0011943. After installing SVC with 190 MVAr at bus 5 according to our proposed algorithm, the voltage profile has been improved very much; as shown in figure 11.

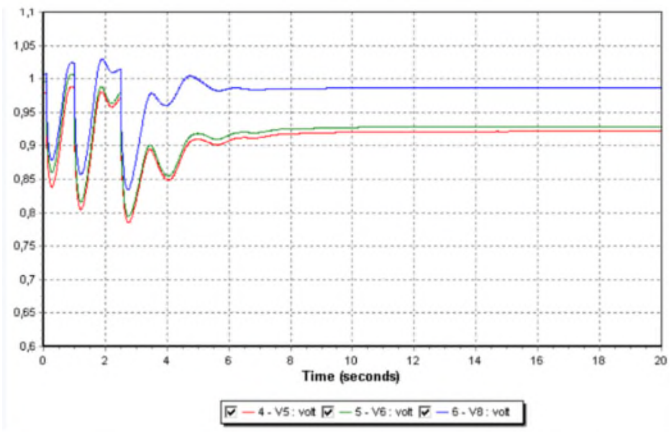

Figure. 10 Case 4: Load bus voltages before SVC installation.

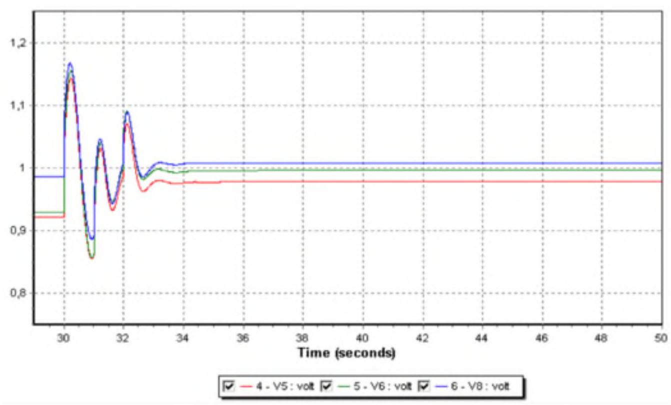

Figure. 11 Case 4: Load bus voltages after SVC installation.

6. CONCLUSIONS

The simulation results obtained for the four different disturbance sizes are highly satisfactory and align well with previous research findings. It can be confidently stated that placing SVCs based on voltage sensitivities significantly enhances the voltage profile of the power system. Multiple cases have been examined in this study.

In the initial case study, the disturbance magnitude was exceedingly small. The voltage values remained within safe margins, and the system was able to rectify the disturbance using spinning reserve without necessitating SVC installation. In the second case study, the disturbance remained small, and this led to only minor impacts on the load bus voltages. However, in the third and fourth cases, the magnitude of the disturbance was substantial, resulting in voltages dropping to unacceptably low levels.

Nonetheless, upon implementing SVCs, an observable enhancement in the voltage profiles has been noted. Overall, it takes approximately 20 seconds for the system to attain an acceptable voltage level.

Determining the most optimal placement entails considering both voltage stability and real/reactive power losses. Consequently, the application of SVCs in power systems not only bolsters voltage stability but also curtails line losses and augments voltage regulation.

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Based Security Control of Networked Control System under Communication Constraints

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ABSTRACT

In this paper we deal with the security stability when a communication canal is inserted in the control loops which bring some communication constraints such as induced time delays and packets dropout. Those constraints can degrade the performances of the system or take it to instability that is to say that the control system is not secured. With the aim to keep good performances of the controlled system face of possible changes introduced by the network, it is interesting to introduce new approaches or ameliorate and improving some existing results. In this article we are concerned with the security function of the system with stability analysis and stabilization of networked control systems with network induced time-delay. To achieve this goal a novel augmented Lyapunov-Krasovskii functionals (LKF) is considered to derive the proposed delay dependent LMIs based secured stability conditions. Numerical examples and simulation results are presented to illustrate the effectiveness of the method.

1. INTRODUCTION

Feedback control systems wherein, actuators, sensors, controllers and other components are distributed around a digital communication network are called Networked Control Systems (NCSs), that can be shared or not with other applications [1][2][3]. Today's NCSs are widely used in many fields because of its appealing advantages, such as enabling remote data transmission, reducing the cabling complexity, minimizing costs and providing easy maintenance. Although NCSs have many attractive features, such as reduced wiring costs, ease of installation and maintenance and improved system reliability and efficiency, the insertion of a communication channel or network in the control loop has, on the other side, some challenging constraints which can degrade the performances of the control system and cause undesired stability problems[1][4][5].

The main issues addressed by the networked control system research community over the last twenty years are: Information loss and time delay [2-4]. Both constraints are causes for instability and performance degradation and the objective is to propose adequate methodologies for the modeling, analysis and design of networked systems that are more complex than the traditional wired architecture [4][8].The issue packet dropouts arises in NCSs because analog signals are sampled, quantized and organized into information packets before transmission via the network according to specific data communication protocols.It is therefore necessary to propose appropriate control strategies for guarding a secured system function in presence of time delay and packet dropouts. The second issue is the network-induced delay, including sensor-to-controller delay and controller-to-actuator delay that occurs when data exchange happens among devices connected by the communication network, this delay, depending on the network characteristics such as network load, topologies, routing schemes, and it can be constant, time-varying, or even random [2,3].

The main objective of this thesis is to propose computationally efficient stability and stabilization criteria for linear networked control systems. We address systems with constant sampling rates, data packet losses, and varying time delays. In literature, most researches works dealt with time delay and packets dropout separately, in this context our first contribution is to take into account those two constraints simultaneously, by considering packet dropout as a time delay.

It is clear that the stability analysis and stabilization are important issues in analysis and design of networked control system with time delay. In general, there are two ways for the stability analysis and control synthesis of time-delay NCSs models, they are delay-independent and delay-dependent approaches. For both approaches, they have their own advantages on dealing with time-delay NCSs models. Much attention has been paid to the study of delay-dependent stability and stabilization for time-delay systems because delay-dependent results for time-delay systems are less conservative than those for the delay-independent cases, especially for time-delay systems with actually small delay.

In this paper, we present a technique where the forward network-induced delay in the control loop is taken into consideration for the design of a stabilizing state feedback delay-dependent control law by resolution of a feasible set of linear matrix inequalities (LMIs)[8-10]. These LMIs are derived by using an appropriate Lyapunov functional for the closed-loop time-delayed system. The solution of the LMI control problem can be obtained using the LMI toolbox available in MATLAB.

The rest of the paper is organized as follows. The control problem is formulated in section II. Section III deals with the delay dependent conditions of state feedback stabilization. Numerical example and simulation are presented in section IV to illustrate the theoretical results, and conclusions are drawn in section V.

NOTATION.

In this paper, $\mathbb{R}^n$ and $\mathbb{R}^{nxm}$ denote, respectively, the n dimensional Euclidean space and the set of nxm real matrices. The superscript "T" denotes matrix transposition and the notation $X > 0$ (respectively, $X \geq 0$) w here X is a symmetric matrix, means that X is positive definite (respectively, positive semi-definite). The symbol * will be used for symmetric terms in the LMIs.

2. PROBLEM STATEMENT

In this section, lest we consider the following continuous-time system:

$$\begin{cases} \dot{x}(t) = Ax(t) + Bu(t) \\ y(t) = Cx(t) \end{cases} \quad (1)$$

Where:

$x(k)\epsilon R^n$, $u(k)\epsilon R^m$, $y(k)\epsilon R^l$ are states, control and output vectors of the system and $A\epsilon R^{nXn}$, $B\epsilon R^{nXr} C\epsilon R^{mXn}$ are known matrices. The system's initial condition is specified by $x(0) = x_0$.

The total variable time delay denoted by τ(t) is the sum of the two variable time delay from sensor to controller τ_1 and from controller to actuator τ_2 and will be assumed to satisfy:

$$\tau_{min} \leq \tau(t) \leq \tau_{max}$$

$$0 \leq \tau(t) \leq h \quad , \ \dot{\tau}(t) \leq \mu < \infty \quad (2)$$

With h and μ constant parameters.

In this paper, the goal is to investigate the control ofthe linear system (1),according to the networked control scheme presented in Figure 1. In this context, wewill consider the following assumptions.

ASSUMPTION1 All the state variables are available from measurements and transmitted to the controller

ASSUMPTION2 The sensors are clock driven; the controller and actuators are event driven

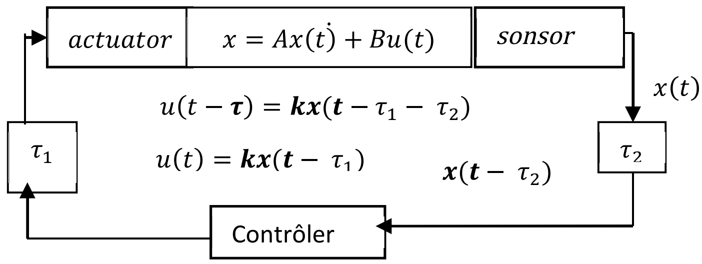

Figure1. Structure of the NCS with network-induced Time delay

To stabilize (1) over the network, let us consider the Following sampled state feedback control law

$$u(t) = Kx(t)(3)$$

Where k is the matrix gain and $\tau(t)$ is the total time delay to be computed with $\tau(t) = \tau_1 + \tau_2$.The objective is to design a state feedback controller given

$$u(t) = Kx(t - \tau(t))(4)$$

Such that the closed loop system shown in figure (1) is Asymptotically stable. Substituting the controller expression (3) into (1), we get the following closed-loop Dynamics:

$$\begin{cases} \dot{x}(t) = Ax(t) + BKx(t - \tau(t)) \\ x(s) = \varphi(s) , \quad -h \leq s \leq 0 \end{cases} \quad (5)$$

3. MAIN RESULTS

In this section, we will first focus on the stability analysis of the closed-loopNCS (7) (assuming the controller gain K known). Then, the stability conditions will be convexified to allow the design of the controller gain K.

3.1DELAY-DEPENDENT STABILITY CONDITION

This section present new delay-dependent stability conditions ofNCS time-delay models. The following lemmas are useful to obtain our results.

Lemma 1[1]: For any constant matrix $M > 0$, any scalars a and b with $a < b$, and any vector function $x(t):[a\ b] \to R^n$ such that the integrals concerned are well defined, then, the following inequality holds:

$$\left[\int_a^b x(s)ds\right]^T M \left[\int_a^b x(s)ds\right] \leq (b-a)\int_a^b x^T(s)Mx(s)ds$$

Lemma2 [2]:For any constant matrices $Q_{11}, Q_{22}, Q_{12} \in R^{n\times n}$, $Q_{11} \geq 0,\ Q_{22} \geq 0, \begin{bmatrix} Q_{11} & Q_{12} \\ * & Q_{22} \end{bmatrix} \geq 0,$ scalar $\tau(t) \leq \tau_0$ and vector function $\dot{x}:[-\tau_0 \quad 0] \to R^n$ such that the following integration is well defined, then

$$-\tau_0 \int_{t-\tau_0}^{t} \begin{bmatrix} x^T(s) & \dot{x}^T(s) \end{bmatrix} \begin{bmatrix} Q_{11} & Q_{12} \\ * & Q_{22} \end{bmatrix} \begin{bmatrix} x(t) \\ \dot{x}(t) \end{bmatrix} ds \leq$$

$$\begin{bmatrix} x(t) \\ x(t-\tau) \\ \int_{t-\tau(t)}^{t} x(t)ds \end{bmatrix}^T \begin{bmatrix} -Q_{22} & Q_{22} & -Q^T{}_{12} \\ Q_{22} & -Q_{22} & Q^T{}_{12} \\ -Q_{12} & Q_{12} & -Q_{11} \end{bmatrix} \begin{bmatrix} x(t) \\ x(t-\tau) \\ \int_{t-\tau(t)}^{t} x(t)ds \end{bmatrix}$$

NEWTON-LEIBNITZ FORMULA

The Newton-Leibnitz Formula gives us

$$\int_{t-\tau(t)}^{t} \dot{x}\,(t)dt - x(t-\tau(t) - x(t) = 0$$

For any appropriately dimensioned matrices N1 and N2, the following is true:

$$2[\dot{x}^T(t)N_1 + x^T(t-\tau(t)N_2] \quad [x(t) - \int_{t-\tau(t)}^{t} \dot{x}\,(t)dt - x(t-\tau(t)] = 0$$

In the next theorem, the terms on the left side of this equation are added tothe derivative of the Lyapunov-Krasovskii functional. The FWMs, N1 and N2, indicate the relationships among the terms of the Newton-Leibnitz formula; and optimal values for them can be obtained bysolving LMIs. The proposed LMI-based stability conditions of the NCS assuming the controller gain K known are summarized by the following theorem.

THEOREM 1 for given scalarsτ and $h$as well as the given matrices K_i the closed-loop system(4)is asymptotically stable if there exist positive definite matrices $\mathrm{P} = P^T > 0$, $Q > 0\mathrm{R} > 0$ and $\mathrm{S} > 0$ and, matrices W_1, W_2, W_3 Such that the following LMI holds:

$$M = \begin{bmatrix} M_{11} & M_{12} & M_{13} & M_{14} \\ * & M_{22} & M_{23} & M_{24} \\ * & * & M_{33} & M_{34} \\ * & * & * & M_{44} \end{bmatrix} < 0$$

Where:

$$M_{11} = A^T P + P^T A + Q + R - W_1 - W_1^T + hA^T SA$$

$$M_{12} = W_1^T - W_2 + PBK + hA^T SBK,\ M_{13} = -W_3,$$

$$M_{14} = W_1^T$$
$$M_{22} = -(1-\mu)Q + W_2 + W_2^T + hK^T B^T SBK,$$
$$M_{23} = W_3, M_{24} = W_2^T,$$
$$M_{33} = -R,\ M_{34} = W_3^T,\ M_{44} = -\frac{1}{h}.S$$

PROOF: To prove the theorem, let swe propose the following Lyapunov–Krasovskii functional candidate**:**

$$V(x(t)) = V_1(x(t)) + V_2(x(t)) + V_3(x(t)) + V_4(x(t)) \quad (7)$$

Where

$$V_1(x(t)) = x^T(t)Px(t) \quad (8)$$
$$V_2(x(t)) = \int_{t-\tau(t)}^{t} x^T(s)Qx(s)ds \quad (9)$$
$$V_3(x(t)) = \int_{t-h}^{t} x^T(s)Rx(s)ds \quad (10)$$
$$V_4(x(t)) = \int_{-h}^{0}\int_{t+\theta}^{t} x^T(s)S\dot{x}(s)ds\, d\theta \quad (11)$$

REMARK

There are four important points regarding the Development of model transformations. When double-integral terms are introduced into the Lyapunov-Krasovskii functional to produce a delay-dependent stability condition, it results in quadratic integral terms appearing in the derivative of that functional. Model transformations emerged as a way of dealing with those quadratic integral terms. More specifically, the purpose of a model transformation is to bring the integral terms into the system equation so as to produce cross terms and quadratic integral terms in the derivative of the Lyapunov-Krasovskii functional. Then, the bounding of the cross terms eliminates the quadratic integral term.

The LKF candidate (7) is positive if P, Q, R, S, are all positive definite matrices. Moreover, the NCS model with network-inducedelay is asymptotically stable if:

$$\dot{V}(x(t)) = \dot{V}_1(x(t)) + \dot{V}_2(x(t)) + \dot{V}_3(x(t)) + \dot{V}_4(x(t)) < 0$$

Calculating the derivative of $V(x(t))$ along the solution of system (3) yields

$$\dot{V}(x(t) = \dot{V}_1(x(t)) + \dot{V}_2(x(t)) + \dot{V}_3(x(t)) + \dot{V}_4(x(t))$$

Where

$$\dot{V}_1(x(t)) = x^T(t)[A^T P + AP]x(t) \quad (12)$$
$$+ 2x^T(t)PBKx(t-\tau(t)) < 0$$

$$\dot{V}_2(x(t)) = x^T(t)Qx(t) \quad (13)$$
$$- (1-\dot{\tau}(t))x^T(t-\tau(t))Qx(t-\tau(t))$$
$$\leq x^T(t)Qx(t)$$
$$- (1-\mu)x^T(t - \tau(t))Qx(t-\tau(t)) < 0$$

$$\dot{V}_3(x(t)) = x^T(t)Rx(t) - x^T(t-h)Rx(t-h) < 0 \quad (14)$$

$$\dot{V}_4(x(t)) = h\dot{x}^T(t)S\dot{x}(t)) - \int_{t-h}^{t} \dot{x}(s)S\dot{x}(s)ds$$
$$\leq x^T(t)hA^T SAx(t) + x^T(t)hA^T SBKx(t-\tau(t))$$
$$+ x^T(t-\tau(t))hK^T B^T SAx(t)$$

$$+x^T(t-\tau(t))hK^TB^TSBKx(t-\tau(t))$$

$$-\frac{1}{h}(\int_{t-\tau(t)}^{t}\dot{x}(s)ds)^TS(\int_{t-\tau(t)}^{t}\dot{x}(s)ds) \quad (15)$$

So the final time derivative of Lyapunov Krasovskii function is given By

$$\dot{V}(x(t)) \le x^T(t)M_{11}x(t) + x^T(t)M_{12}x(t-\tau(t))$$

$$+x^T(t)M_{13}x(t-h) + x^T(t)M_{14}\left(\int_{t-\tau(t)}^{t}\dot{x}(s)ds\right)$$

$$+x^T(t-\tau(t))M_{12}^Tx(t) + x^T(t-\tau(t))M_{22}x(t-\tau(t))$$

$$+x^T(t-\tau(t))M_{23}x(t-h)$$

$$+x^T(t-\tau(t))M_{24}\left(\int_{t-\tau(t)}^{t}\dot{x}(s)ds\right)$$

$$+x^T(t-h)M_{13}^Tx(t) + +x^T(t-h)M_{23}^Tx(t-\tau(t))$$

$$+x^T(t-h)M_{33}x(t-h) + x^T(t-h)M_{34}\left(\int_{t-\tau(t)}^{t}\dot{x}(s)ds\right)$$

$$+\left(\int_{t-\tau(t)}^{t}\dot{x}(s)ds\right)^T M_{14}^Tx(t)$$

$$+\left(\int_{t-\tau(t)}^{t}\dot{x}(s)ds\right)^T M_{24}^Tx(t-\tau(t))$$

$$+\left(\int_{t-\tau(t)}^{t}\dot{x}(s)ds\right)^T M_{34}^Tx(t-h)$$

$$+\left(\int_{t-\tau(t)}^{t}\dot{x}(s)ds\right)^T M_{44}^T\left(\int_{t-\tau(t)}^{t}\dot{x}(s)ds\right)(16)$$

As we can see the whole derivative contain some noun quadratic integral terms, those terms must be treated securely to get at least a quadratic from of the time derivative of the Lyapunov function.

By using lemma 1 and lemma2 and by exploiting Newton Leptniz formula,the expression ofthe time derivative of the Lyapunov function can be rewritten as follows:

$$\dot{V}(x(t) \le \eta^T(t)M\eta(t) \qquad (17))$$

With

$$\eta(t) = [x^T(t)\ \ x^T(t-\tau(t))\ \ x^T(t\,)\left(\int_{t-\tau(t)}^{t}\dot{x}(s)ds\right)^T]^T$$

Which indicates that the derivative $\dot{V}(x(t)$ is strictly negative and, the Lyapunov functional is decreasing ifufficiency matrix M is negative definite.
This completesthe proof of theorem 3.1.

3.2. CONTROLLER DESIGN

The following theorem gives equivalent LMI condition for the design of the state feedback controller.

THEOREM 2

Let **ϵ** be a given positive scalar. There exists a stabilizing state feedback controller for the closed-loop networked control system if there exist matrix $\mathbf{X} > \mathbf{0}$, matrices $\overline{\mathbf{W}}_\mathbf{1}$, $\overline{\mathbf{W}}_\mathbf{2}$, $\overline{\mathbf{W}}_\mathbf{3}$ and matrices $\overline{\mathbf{Q}} > \mathbf{0}\overline{\mathbf{R}} > \mathbf{0}$ and $\overline{\mathbf{S}} > \mathbf{0}$ such that the following set of LMIs hold:

$$\overline{M} = \begin{bmatrix} \overline{M}_{11} & \overline{M}_{12} & \overline{M}_{13} & \overline{M}_{14} & XA^T \\ * & \overline{M}_{22} & \overline{M}_{23} & \overline{M}_{24} & (BY)^T \\ * & * & \overline{M}_{33} & \overline{M}_{34} & 0 \\ * & * & * & \overline{M}_{44} & 0 \\ * & * & * & * & -\frac{1}{\varepsilon}X \end{bmatrix} < 0$$

$$h\bar{S} < \varepsilon X, \varepsilon > 0$$

Where

$$\overline{M}_{11} = XA^T + AX + \bar{Q} + \bar{R} - \overline{W}_1 - \overline{W}_1^T\ ,$$

$$\overline{M}_{12} = \overline{W}_1^T - \overline{W}_2 + BY$$

$\overline{M}_{13} = -\overline{W}_3,\ \ \overline{M}_{14} = \overline{W}_1^T,$
$\overline{M}_{22} = -(1-\mu)\bar{Q} + \overline{W}_2 + \overline{W}_2^T,\ \ \overline{M}_{23} = \overline{W}_3,\ \ \overline{M}_{24} = W_2^T$

$\overline{M}_{33} = -R\ ,\quad \overline{M}_{34} = \overline{W}_3^T,\quad \widetilde{M}_{44} = -\frac{1}{h}\bar{S}$

The stabilizing controller gain is given by$K = YX^{-1}$.
The proof of theorem2.Relies on finding equivalent LMI conditions based on the Schur complement theorem. For this purpose, note that the previous LMI can be rewritten:

$$M = \begin{bmatrix} \widetilde{M}_{11} & \widetilde{M}_{12} & \widetilde{M}_{13} & \widetilde{M}_{14} \\ * & \widetilde{M}_{22} & \widetilde{M}_{23} & \widetilde{M}_{24} \\ * & * & \widetilde{M}_{33} & \widetilde{M}_{34} \\ * & * & * & \widetilde{M}_{44} \end{bmatrix}$$

$$+\begin{bmatrix} A^T \\ (BK)^T \\ 0 \\ 0 \end{bmatrix}[hs][A\ BK\ 0\ 0] < 0$$

Where:

$\widetilde{M}_{11} = A^TP + P^TA + Q + R - W_1 - W_1^T\ ,\qquad \widetilde{M}_{34} = W_3^T$

$\widetilde{M}_{12} = W_1^T - W_2 + PBK\ \ ,\ \widetilde{M}_{13} = -W_3\widetilde{M}_{14} =\ W_1^T$

$\widetilde{M}_{22} = -(1-\mu)Q + W_2 + W_2^T\ ,\ \widetilde{M}_{24} =\ W_2^T$

$\widetilde{M}_{33} =\ -R\ \ ,\widetilde{M}_{44} = -\frac{1}{h}.S$

Letting $X = P^{-1}$ and, pre- and post-multiplying (12) by X we get:$h\bar{S} < \varepsilon X, \varepsilon > 0$Where$\bar{S} < X.S.X.$
Then, by Schur complement, (11) is equivalent to the following LMI:

$$\begin{bmatrix} \widetilde{M}_{11} & \widetilde{M}_{12} & \widetilde{M}_{13} & \widetilde{M}_{14} & A^T \\ * & \widetilde{M}_{22} & \widetilde{M}_{23} & \widetilde{M}_{24} & (BK)^T \\ * & * & \widetilde{M}_{33} & \widetilde{M}_{34} & 0 \\ * & * & * & \widetilde{M}_{44} & 0 \\ A & BK & 0 & 0 & -1/\varepsilon P^{-1} \end{bmatrix} < 0 \qquad (18)$$

Now, let $Y = KX$,$\bar{Q} = XQX$, $\bar{R} = XRX$, $\bar{W}_1 = XW_1X$, $\bar{W}_2 = XW_2X$ and $\bar{W}_3 = XW_3X$. Pre-and post-multiplying (18) by Diag(X, X, X, X, I) yields the LMI condition .The set of LMIs (9) and (10) are linear in the unknown matrices X , Y , $\bar{W}_1$,$\bar{W}_2$,$\bar{W}_3$, $\bar{Q}$, $\bar{R}$ and $\bar{S}$ can be solved using the LMI MATLAB toolbox and the stabilizing gain matrix is computed as$K = YX^{-1}$.

3. Simulation Example

In This section, we present a numerical example to demonstrate the effectiveness and applicability of the proposed theory over an inverted pendulum system.
The plant to study is sketched in Figure (2). The pendulum carried by a cart is allowed to rotate about its axis. The cart moves horizontally by means of a belt and a motor which applies a force F (t). The mathematical model of the mechanical system is deduced by application of the fundamental principle of dynamics and the balance of forces involved. The cart position and the angle of the inverted pendulum are denoted by x and θ , respectively. The linearization of the system model about its equilibrium leads to the following linear time-invariant state space model where, the state vector is given by:

x : cart position
θ: Pendulum angle
F: Force applied to the cart

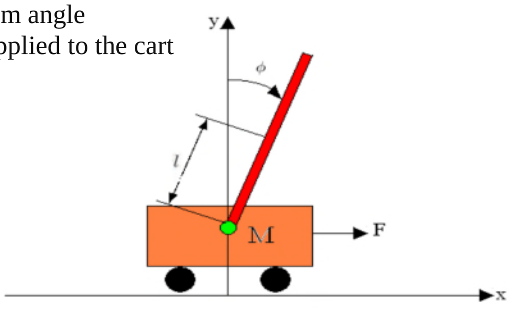

Figure (2): Structure of the linear inverted pendulum

$$[x_1\, x_2 x_3\, x_4]^T = [\theta\ \ \dot{\theta}\ \ x\ \ \dot{x}]^T$$

The physical linear model in the state spaceis given by :

$$\begin{bmatrix} \dot{x_1} \\ \dot{x_2} \\ \dot{x_3} \\ \dot{x_4} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ M+m/MI & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ -Mg/m & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} 0 \\ -1/MI \\ 0 \\ 1{:}\,M \end{bmatrix} u$$

For simulrion we will assum that $g = 9.81$; $m = 0.1kg$; $M = 2kg$; $2l = 1m$ in this case we get

$$A = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 20.601 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ -0.4905 & 0 & 0 & 0 \end{bmatrix} , B = \begin{bmatrix} 0 \\ -1 \\ 0 \\ 0.5 \end{bmatrix}$$

This system is open-loop unstable, where the state variables of the free system increase indefinitely from the initial state However, this control law is unable to stabilize the system when the sensor transmits the state information to the controller via a communication network that induces a delay of a maximum value h = 60ms in the control loop.as shown in figure (3).

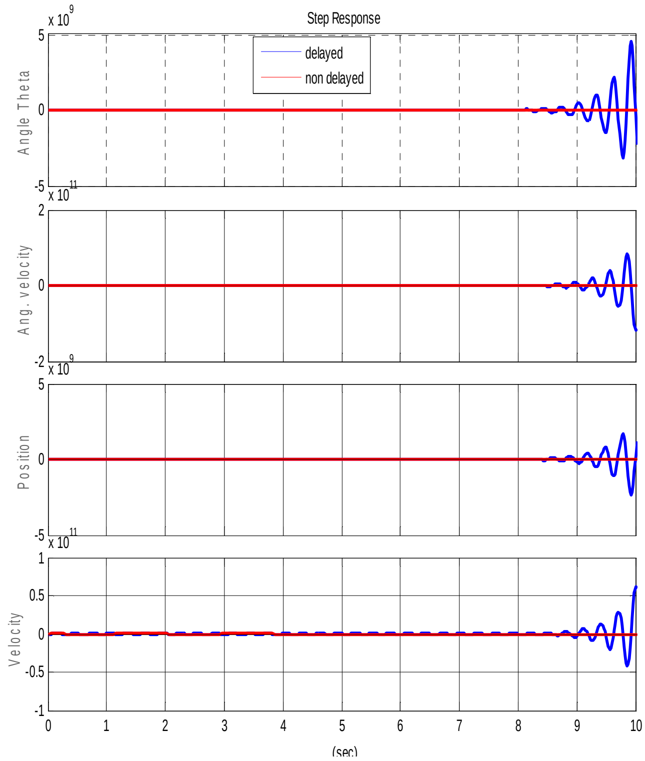

Fig. 3Unstable closed-loop delayed system (h=60ms)

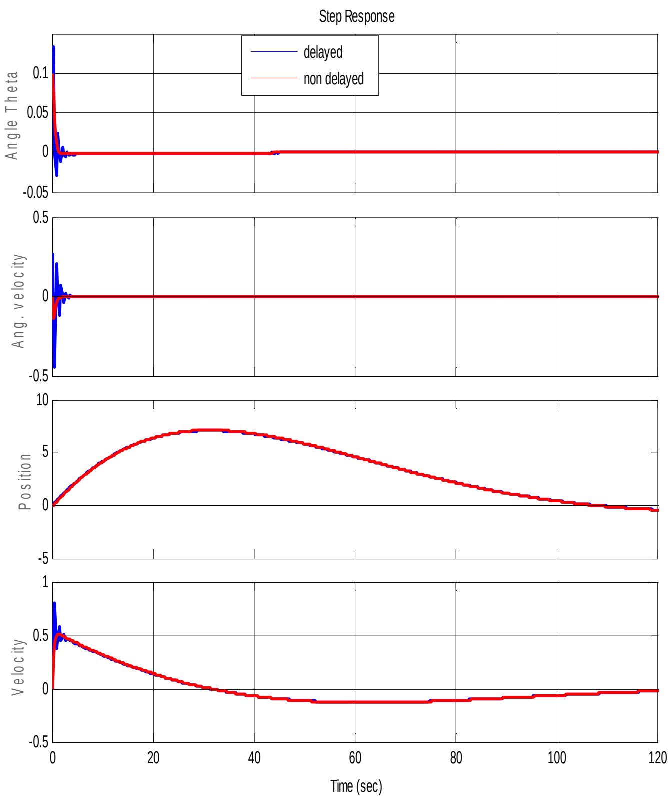

Fig. 4 Stable closed-loop system under network Induced Delay constraint (h=125ms)

The response of the closed-loop system with the designed control law and under initial conditions is shown in Fig.6

We can see the stable response of the system from the initial position, when driven by a controller gain matrix computed by applying the LMI technique developed in the theory. The stabilizing gain matrix is given by

$$K_{LMI} = [35.1561\ 7.7472\ \ 0.0020\ 0.0671]$$

This controller is able to stabilize the inverted pendulum controlled via a communication network that induces a transmission delay varying in the interval 0ms to 125ms

4. Conclusion

This paper dealt with the secured stability and stabilization of networked control systems by state-feedback control under the constraint communication packet loss and delay induced in the sensor-to-controller path. The delay considered is time varying and bounded. The stabilization control problem is studied and sufficient conditions are derived in the form of linear matrix inequalities (LMIs). The sufficient conditions are delay-dependent. Future work includes extension to the general case of network-induced delays in both forward and backward paths.

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Studies and Analysis of the MPPT based DISMC of PV using Buck Converter connected to Battery

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Photovoltaic (PV), Buck converter, MPPT, P&O algorithm, DISMC , Battery, MATLAB, Simulink.

ABSTRACT

This paper presents a detailed modeling of the MPPT based on the DISMC technique applied to a stand-alone PV system with a DC-DC buck converter , to reveal the best performances experiencing fast convergence, fast transient response and robustness to variable climatic conditions, such as irradiation . Improving PV power requires robust MPP tracking. Most techniques used to achieve MPPT have some drawbacks , DISMC's strategy is to design a sliding surface that fixes the operating point. Reaching this surface in finite time requires a control law applied to the grid of the DC/DC converter. A buck converter is used as the DC-DC converter for the load system. It is used to match the impedance of the solar panel and the battery to provide maximum power. The objective of this work is to improvement of the power quality under different conditions . The simulation results on Matlab/Simulink are presented and discussed.

1. INTRODUCTION

The growing demand for electrical energy and the constraints associated with its production, such as pollution and the effects of global warming, have prompted research into the development of renewable energies. Among renewable energy sources, photovoltaic (PV) systems offer a highly competitive solution.

Interest in renewable energies continues to grow. Efforts are being made to develop clean, efficient and inexpensive energy sources. Solar energy has long been a key area of research, and research in this field continues to accelerate. Lead-acid batteries are still popular, although lithium-ion batteries are also being tested, but cost is the decisive factor. Solar energy is harnessed by stand-alone photovoltaic systems [1].Photovoltaic panels convert solar energy into electricity. Photovoltaic systems have non-linear internal characteristics [2]. Irradiance, temperature and power characteristics in solar photovoltaic systems. Due to the high cost of photovoltaic panels, maximum power point tracking (MPPT) is required to track maximum power output [4]. DC/DC converters are connected to photovoltaic panels and batteries. Lead-acid batteries are the most commonly used because of their wide operating temperature range, low self-discharge, long service life and low maintenance requirements [5] . Batteries are cheaper to install than photovoltaic panels. But compared with photovoltaic panels, the lifetime cost of batteries is higher [6].

Photovoltaic systems also have a limited service life. If the availability of photovoltaic energy is low for a long period, or if charging and discharging are inadequate, battery life will be shortened [7]. Or incorrect charging and discharging. Charging the battery The battery charge must be controlled to achieve a high state of charge and longer battery life [8]. (SOC) and longer battery life. The main objective is to charge the battery safely using solar energy. This report presents the modeling of an MPPT battery charge controller in Simulink [9]. A step-down converter supplying 12V to the battery. Power conversion Power conversion is performed by a step-down converter [10]. In the proposed system, a photovoltaic model, a battery model and a battery charging system designed with a step-down converter are implemented. It requires a DISMC control method to extract the maximum power point from MPPT.

The main aim of this study is to determine how the controller reacts to sudden variations in solar irradiance and temperature, to attenuate undesirable oscillations caused by DC/DC converter switching and/or the controller itself, and to determine the response time. The simulations were carried out using MATLAB-SIMULINK, and the results are presented in this report. The simulation is carried out using MATLAB/Simulink.

2. MODELING OF THE GPV

Figure 1 shows the method adopted in this report for charging batteries by detecting the battery charging current. MPP tracking systems are used to increase the maximum power produced by the solar panel. Even if temperature, irradiation and load characteristics vary, this keeps the output of the photovoltaic solar panel at a constant level. constant. For greater efficiency of the PV panel output, a buck converter is used to transmit DC-DC energy. In stand-alone photovoltaic systems, buck converters are effective in DC step-down and transmission operations and , battery storage . tracking solar energy from photovoltaic panels. PV panel, many MPPT techniques are available, disturbance and observation, incremental conductance algorithm, etc.. Among all the control algorithms, the DISMC method is the most efficient than simple control algorithms.

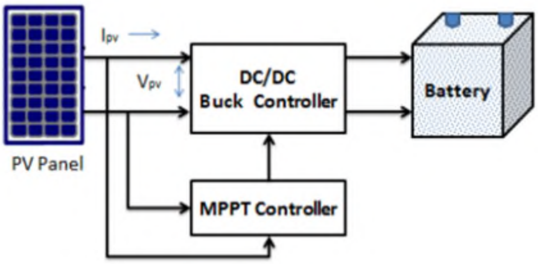

Figure. 1. Block diagram of the system

3. CHARACTERISTICS OF PV PANEL

The modeling of PV parameters is taken from the article [11-12]. The single-diode model is considered (See Figure 2) because of its advantages: simplicity of design and ease of analysis of PV performance. There are four parameters required to model the single diode circuit PV [13].

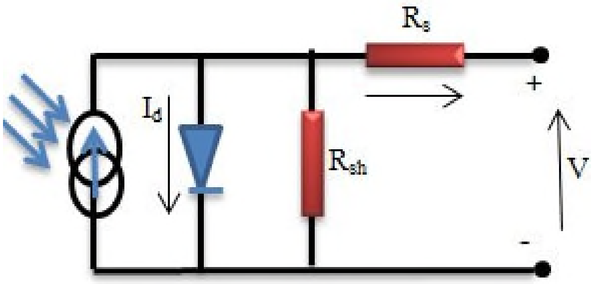

Figure.2 Equivalent diagram of a PV cell

$$I_{pv} = I_{ph} - I_0[e^{(\frac{q(V_{pv}+I_{pv}R_S)}{nkT})} - 1] - \frac{V_{pv}+I_{pv}R_S}{R_{sh}} \quad (1)$$

Where,

I_{ph}:photocurrent;

I_0:diodesaturationcurrent;

Ipv:terminalcurrent;

V_{pv}:voltageacrosstheoutputterminal; (5)

R_s:moduleseriesresistance;

R_{sh}:moduleshuntresistance;

N_s : number of cells in one module ;

n: diodeidealityfactor ;

k : Boltzmann's constant ;

T : absolutetemperature;

q:elementarycharge;

Le logiciel MatLab/Simulink est utilisé pour la programmation des cellules PV et des GPV. Les caractéristiques I-V et P-V. sont illustrées par la figure 3.

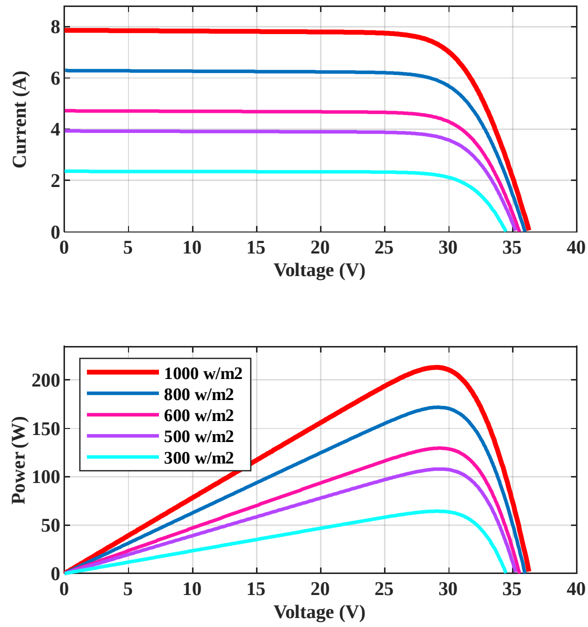

Figure . 3. Variation in P-V curves

4. MPPT BASED DOUBLE INTEGRAL SLIDING MODE CONTROLLER

For maximum power output, the proposed MPPT model based on DISMC is implemented in Matlab/Simulink. This algorithm was developed to eliminate the chatter caused by inverter switching, which is expressed as a nuisance, when unwanted disturbances occur in PV systems[14] . The sliding mode control system consists of two main parts, the first part consists of extracting the sliding surface through the parameters provided by the DC-DC converter, the second part is the formulation of the control law to drive and maintain the system towards the sliding surface[15] .
The sliding mode S(t) is defined by :

$$S(t) = \{x \setminus S(x,t) = \dot{S}(x,t) = 0\} \quad (2)$$

The sliding surface is chosen to provide maximum output power. The sliding surface is defined by :

$$(\partial P_{pv}/\partial I_{pv}) = 0, \quad (\partial P_{pv}/\partial I_{pv}) = I_{pv}((\partial V_{pv}/\partial I_{pv}) + (V_{pv}/I_{pv})) \quad (3)$$

La surface de glissement est la suivante :

$$S(t,x) = ((\partial V_{pv}/\partial I_{pv}) + (V_{pv}/I_{pv})) \quad (4)$$

For the controller design, the tracking error e is given as follows in equations (5) and (6) :

$$S(x) = e(x),\ e(x) = e(x_1) + e(x_2)$$

$$e(x_1) = \int(\Delta P/\Delta I)dt,\ e(x_2) = \int\left\{\int(\Delta P/\Delta I)dt\right\}dt,\ \begin{cases}\Delta P = P_{pv}(k) - P_{pv}(k-1)\\ \Delta I = I_{pv}(k) - I_{pv}(k-1)\end{cases} \quad (6)$$

Typically, the sliding-mode control law is composed of two terms, the equivalent control term and the discontinuous control term. The DISMC algorithm is used to stabilize the system and push it towards convergence to the desired path at the right time[16].

$$u = u_{eq} + u_n \tag{7}$$

In order to obtain equivalent control, the stability condition must be ensured

$$\begin{cases} S(x) = 0 \\ \dot{S}(x) = 0 \end{cases} \Rightarrow u \cong u_{eq} \tag{8}$$

The equivalent control can be obtained by solving the following algebraic equation:

$$\dot{S} = [dS/dx]^T, \quad \dot{x} = [dS/dx]^T.\left(f(x) + g(x)u_{eq}\right) \tag{8}$$

$$u_{eq} = -\left([dS/dx]^T f(x)\right)/\left([dS/dx]^T g(x)\right) = 1 - \left(K_1 \int S + V_{pv}\right)/V_s \tag{9}$$

Taking into account that discontinuous control to ensure the Lyapunov stability criterion is possible [17], this is given by :

The expression of the discontinuous control law is given by :

$$u_n = K_2.|S|^{\alpha}.\sin g(S), \quad 0 < \alpha < 1 \tag{10}$$

$$\begin{cases} \sin g(S) = 1 & \text{if } S(x) > 0 \\ \sin g(S) = 0 & \text{if } S(x) = 0 \\ \sin g(S) = -1 & \text{if } S(x) < 0 \end{cases} \tag{11}$$

$$u = u_{eq} + u_n = \left[1 + K_2.|S(x)|^{\alpha}.\sin g(S) - \left(K_1 \int S(x)dx + V_{pv}\right)/V_s\right] \tag{12}$$

Where K_1 and K_2 are positive constants

5.DC-DC BUCK CONVERTER

The DC-DC converter converts the DC input voltage source into a higher or lower output voltage. Since the PV generator voltage is higher than the battery voltage, the basic topology of a dc-dc buck converter is illustrated in figure 5. , and consists of a controlled SW switch, an uncontrolled switching diode (D), an inductance L, a capacitance C and a load resistor R .Table 1 shows the parameters used .

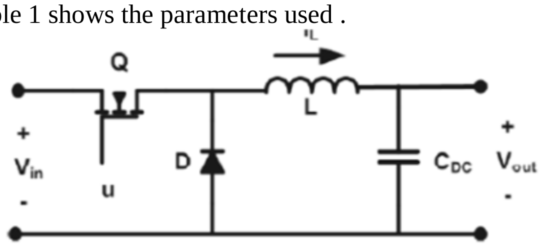

Figure. 4 Buck Converter.

Table 1. Buck converter specification:

Parameter	Value
C_1	1 mF
C_2	369.79 µF
L	0.8653 mH

5. DISCUSSIONS AND RESULTS

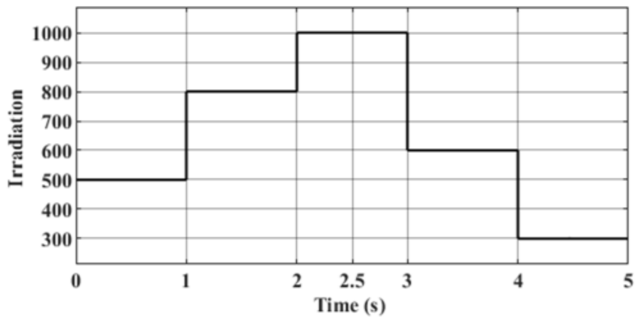

Figure. 5 profil of Irradiation

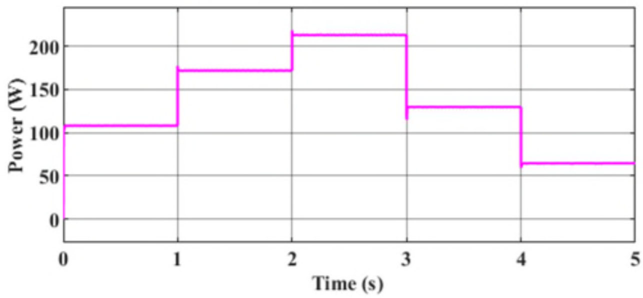

Figure. 6 Power of the PV

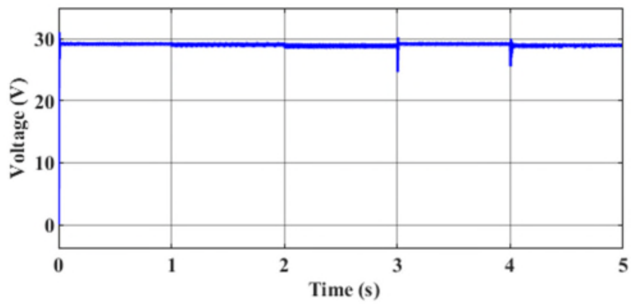

Figure. 7 Voltage of the PV

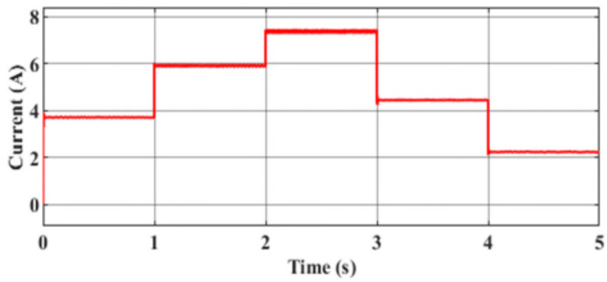

Figure. 8 Current of the PV

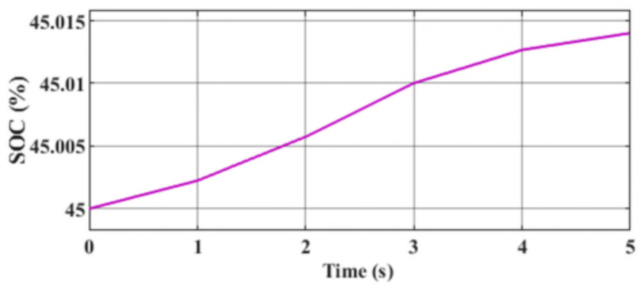

Figure. 9 Battery state of charge

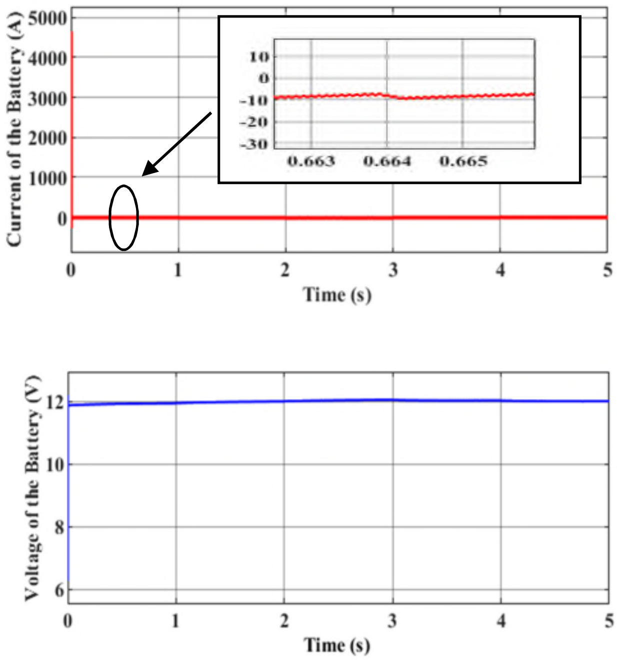

Figure. 10 output Charging Voltage & Current Of battery

The simulation is carried out using MATLAB/Simulink.

This work is carried out in Matlab/Simulink using the parameters listed in Table 2 . An implementation of the proposed controller to verify its performance and robustness against climate change. In this section, we have considered that irradiation evolves according to the profile shown in figure 5, and that photovoltaic power corresponds perfectly to the maximum powers shown in figure 6. Figure 7 and 8 show the photovoltaic current and voltage, which also vary over the course of the previous profile. Figure 9 illustrates Battery state of charge, under the different irradiation values mentioned above.

Figure 10 shows the battery output voltage and current. Here, we focus on the variation times. It can be seen that both current and voltage change as a result of irradiation variation.

6. CONCLUSION

In this work, simulation results obtained with an implementation of the DISMC nonlinear controller as MPPT controller are presented for tracking MPP using a DC/DC boost converter for a system representing a maximum power of 212W. Simulation results are produced using Matlab/Simulink software. This algorithm (DISMC) does not require a reference rung to follow, but it does need to define the sliding surface. This method uses the incremental conductance technique as the sliding surface to track the PPM. The DISMC algorithm offers good performance and robustness through its testing under standard conditions and under conditions of abrupt climatic variation, and has the ability to reduce unwanted oscillations compared with other algorithms.

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Three-Dimensional Fuzzy Logic Controller Applied to Rocket Target Traction

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ABSTRACT

This paper deals with the three-dimensional fuzzy logic technique applications on target traction, where Rocket target traction is a complex process that requires precise control systems to ensure accurate targeting and trajectory. Traditional control systems have limitations in their ability to account for complex and nuanced conditions, leading to less accurate targeting and less efficient use of resources. Three-dimensional fuzzy logic is an advanced approach to control systems that allows for more precise and nuanced evaluations of conditions, leading to more accurate targeting and more efficient use of resources. In this article, we'll explore the application of three-dimensional fuzzy logic to rocket target traction, the benefits of this approach, and examples of its application in real-world scenarios using Matlab.

1. INTRODUCTION

Rocket or Missile trajectory tracking is a critical technology used to guide missiles towards moving targets. The primary objective of missile trajectory tracking is to optimize (minimize) the distance between the missile and the target by calculating the optimal missile trajectory based on the current position and velocity of both the missile and the target. The key component of the guidance system is the tracking algorithm, and it plays a crucial role in achieving high-precision tracking of the target.

There are several types of guidance systems utilized for missile trajectory tracking, including radar, infrared, and laser guidance systems. Each system has its own strengths and limitations based on the flight conditions and target characteristics. Recent research has focused on developing advanced tracking algorithms to improve the precision of missile trajectory tracking. For example, researchers have investigated the use of machine learning techniques to enhance the accuracy of the tracking algorithm. In a recent study, convolutional neural networks were utilized to improve the accuracy of missile trajectory tracking [1].

In addition to developing advanced tracking algorithms, researchers have also explored the use of new sensors and trajectory calculation techniques to improve the recision a of missiles. For instance, a recent combination of missiles. For instance, a recent combination of fuzzy logic controller and a linear quadratic regulator to improve the guidance precision of the missile [2]. Another study proposed a new guidance algorithm based on a sliding mode control approach to improve the control accuracy of the missile [3].

Furthermore, researchers have also investigated the use of multi-sensor fusion techniques to enhance the tracking accuracy of missiles. For example, a recent study proposed a novel multi-sensor fusion algorithm based on a Kalman filter to improve the tracking accuracy of a missile guidance system [4].

So missile trajectory tracking is a critical technology for guiding missiles towards their targets. Advanced tracking algorithms, new sensors, and trajectory calculation techniques are being developed to improve the precision and range of missiles. Future research is expected to focus on developing more sophisticated tracking algorithms and novel guidance techniques to further improve the effectiveness of missile trajectory tracking. And for that this work is devoted to present a new Algorithm based on more developed control technique using the tree-dimensional fuzzy logic[5]-[9].

2. TREE-DIMENSIONAL FUZZY LOGIC

Fuzzy three-dimensional logic, also known as 3D fuzzy logic [10], is an extension of traditional fuzzy logic that allows for modelling three-dimensional systems using three-dimensional fuzzy sets.

Where Fuzzy logic was first introduced in the 1960 as a mathematical framework for dealing with uncertainty and imprecision in data. It was originally developed for use in control systems, where precise, binary decisions were impractical. Fuzzy logic allowed for the creation of control systems that could make more flexible, nuanced decisions based on a range of input data.

In the early 1990s, researchers began to explore the use of fuzzy logic for modelling three-dimensional systems. One of the key challenges in this area was how to represent three-dimensional fuzzy sets mathematically. In 1992, Kaoru Hirota proposed a solution to this problem in a paper titled "Three-Dimensional Fuzzy Control".

Hirota's approach involved dividing a three-dimensional fuzzy set into a series of two-dimensional slices, each of which represented a different level of membership in the set. By representing the fuzzy set in this way, it was possible to perform calculations more efficiently and accurately.

2.1 Description of the Three-dimensional fuzzy logic

Three-dimensional fuzzy logic is an extension of traditional fuzzy logic that allows for the representation of fuzzy sets and membership functions in a three-dimensional space. This approach allows for more complex and nuanced evaluations of degrees of membership. Fuzzy logic is a mathematical approach that deals with uncertainty and imprecision by assigning degrees of truth rather than simply true or false. Traditional fuzzy logic represents fuzzy sets and membership functions in a two-dimensional space. In contrast, three-dimensional fuzzy logic represents fuzzy sets as volumes, called "3D membership functions." 3D membership functions are defined by mathematical equations that describe their shape and position in space. The fuzzy set is then determined by the intersection of several volumes. The fuzzy set of FLC and Type 2 FLc are represented in figure(1) below

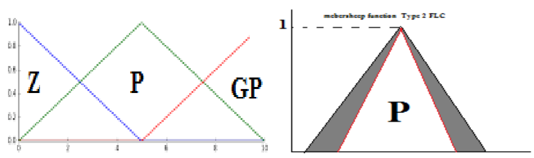

Figure.1classical fuzzy logic set

Where fig 2 represent a tree dimensional fuzzy logic set

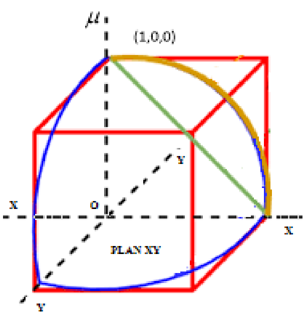

Figure.2 Tree dimensional fuzzy logic set

For the three dimensional axes X, Y, Z each axe has him three dimensional fuzzy set and the controller will use them all in the same time to locate the position of either rocket and target and calculate the optimal estimated trajectory for the rocket.

2.2 Three-dimensional fuzzy logic advantages

The benefits of three-dimensional fuzzy logic include more accurate control and more efficient use of resources. Traditional control systems have limitations in their ability to account for complex and nuanced conditions, leading to less accurate control and less efficient use of resources. Three-dimensional fuzzy logic allows for more precise and nuanced evaluations of conditions, leading to more accurate control and more efficient use of resources but this need more complex algorithms and calculator more powerful to analyse the big data include in lesser time possible.

2.3 Three-dimensional fuzzy logic control principle

The most bases of the fuzzy logic controller are applied on three-dimensional fuzzy logic control but with three dimensional fuzzy set and the needed adaptation on fuzzification, inferences and defuzzification steps as shown on figure(3) below proposed by Volodymyr MORKUN and Olha KRAVCHENKO on 2021 in [11]

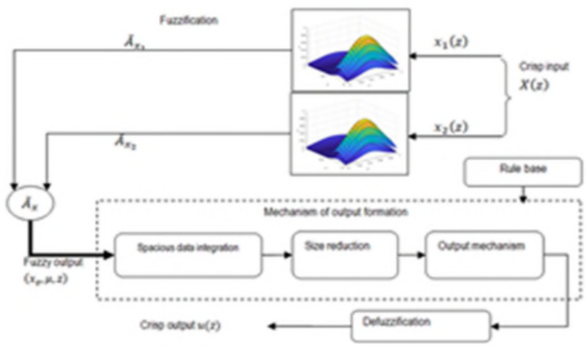

Figure.3 Three-dimensional fuzzy logic control principle [11]

Three-dimensional fuzzy logic is based on mathematical principles, including set theory, fuzzy set theory, and fuzzy logic. Set theory is used to define the universe of discourse, or the set of all possible values of a variable. Fuzzy set theory is used to define fuzzy sets, which are sets that have degrees of membership. Fuzzy logic is used to determine the degree of membership of a value in a fuzzy set.

Where the general basic control structure is represented on fig.4 describe the different parts of the fuzzy logic controller

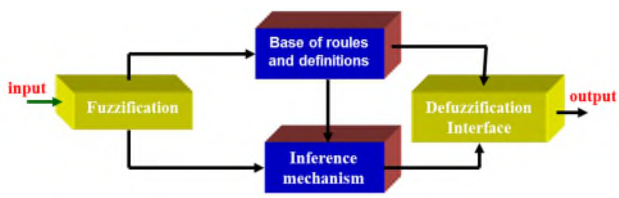

Figure.4fuzzy logic controller structure

Also we can use the different bases rules of the traditional fuzzy logic with the three-dimensional fuzzy logic controller with the consideration of the three dimensional member sheep set function.

3. THREE DIMENSIONAL FUZZY CONTROLER ALGORITHM

Three-dimensional fuzzy logic can be integrated into control systems using mathematical algorithms and programming languages. The algorithms are used to perform calculations and make decisions based on the input data and the fuzzy rule-based system. The programming languages are used to implement the algorithms and create the user interface for the control system.

The proposed controller algorithm steps are described on 7 points below:

Input and output variables definition

1) Member sheep function definition for each variable
2) Member sheep function plot
3) Control rules definition
4) Control rules aggregation
5) Global control rule plot
6) Command calculation
7) Command application to the system

For the input variable we have taken error on position and the error variation with the integral of the error as third input variable

Obtained results are represented in figures 5, 6 and 7

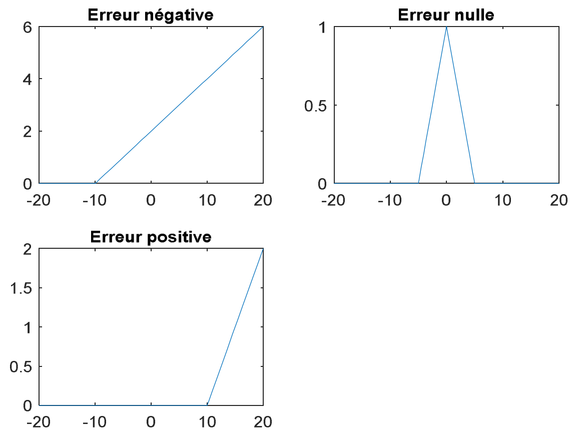

Figure.5 Three-dimensional fuzzy logic control input set ''error''

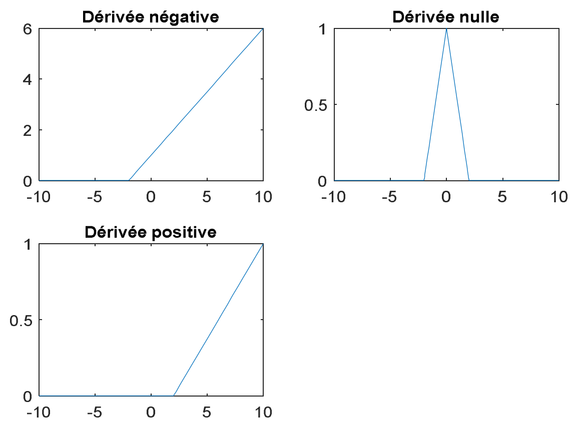

Figure.6 Three-dimensional fuzzy logic control input set''de''

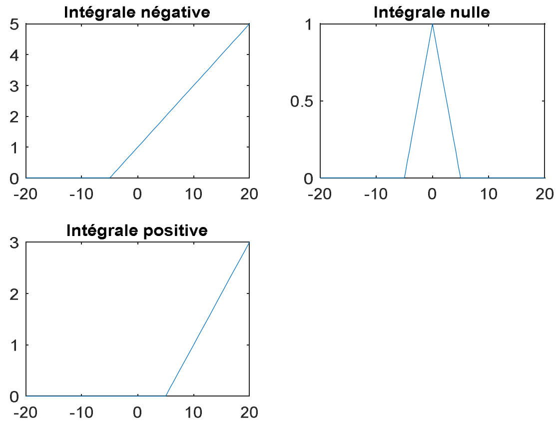

Figure.7 Three-dimensional fuzzy logic control input set ''error integral''

Where the command output is represented by figure.8

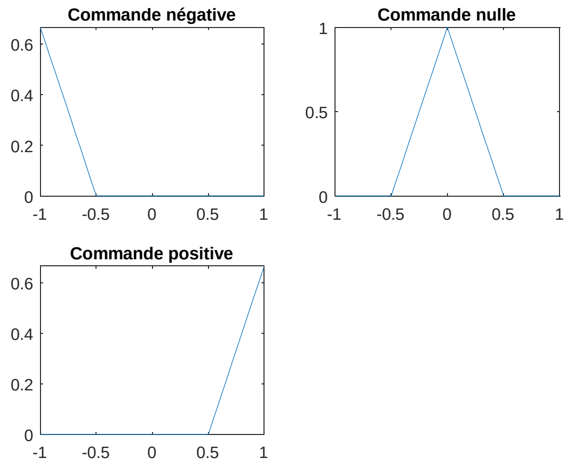

Figure.8 Three-dimensional fuzzy logic control output set ''u''

And the control rules are represented on figure.9

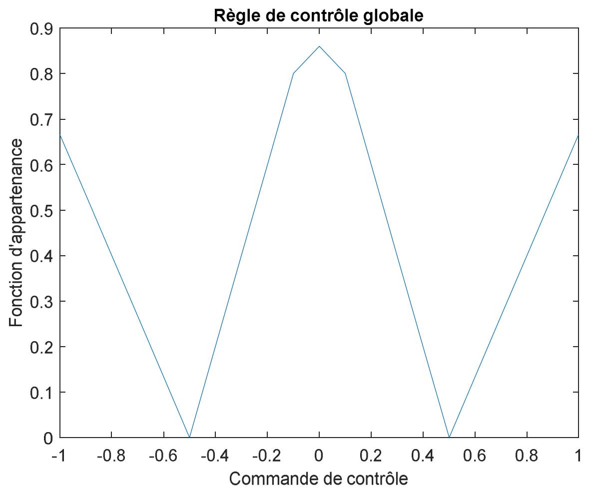

Figure.9 Three-dimensional fuzzy logic global control rules

4. THREE-DIMENSIONAL FUZZY LOGIC APPLIED TO ROCKET TARGET TRACTION

Three-dimensional fuzzy logic can be implemented in rocket target traction by creating 3D membership functions for each variable that affects the trajectory of the rocket. These variables may include altitude, velocity, trajectory, wind speed, and direction. The 3D membership functions are then combined to create a fuzzy rule-based system that determines the optimal thrust, angle, and direction of the rocket.

As example of the application of three-dimensional fuzzy logic to rocket target traction is the landing of the Mars Rover on the surface of Mars. The landing process involves multiple stages, including entry, descent, and landing. During the descent stage, the rocket engine must be controlled to ensure a safe and accurate landing. Three-dimensional fuzzy logic can be used to regulate the thrust of the rocket engine based on observed measurements, such as altitude, velocity, and trajectory. It can also be used to adjust the angle and direction of the rocket in response to changing conditions, such as wind speed and direction.

The Mars Pathfinder mission, launched in 1996, utilized fuzzy logic to control the descent of the spacecraft onto the surface of Mars. The fuzzy logic system was used to adjust the thrusters of the spacecraft to keep it on course as it descended towards the surface. The system was able to adjust to unexpected wind gusts and keep the spacecraft on target, resulting in a successful landing.

5. CONCLUSIONS

Three-dimensional fuzzy logic is an advanced approach to control systems that allows for more precise and nuanced evaluations of conditions, leading to more accurate targeting and more efficient use of resources. It can be applied in many fields, including rocket target traction, where it can be used to regulate the thrust, angle, and direction of the rocket engine based on observed measurements. The mathematical integration of three-dimensional fuzzy logic in control systems is based on set theory, fuzzy set theory, and fuzzy logic, and can be implemented using mathematical algorithms and programming languages. With its ability to handle complex and nuanced conditions, three-dimensional fuzzy logic has the potential to revolutionize the field ofcontrol systems and improve the accuracy and efficiency of many processes.

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