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Smart electric vehicle charging scheduler for overloading prevention of an industry client power distribution transformer

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HIGHLIGHTS

- An industry client power distribution transformer in a Portuguese island is addressed.
- A new smart electric vehicle (EV) charging scheduler is proposed.
- Real data are used for the main inputs of the model, including power transformer and EV parameters.
- The proposed solution allows avoiding the overloading of the power transformer.

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ABSTRACT

In this paper an overloading prevention of a private customer power distribution transformer (PDT) in an island in Portugal through the means of a new smart electric vehicle (EV) charging scheduler is proposed. The aim of this paper is to assess the repercussion of the penetration of additional power to restore the full level of EV battery state of charge (SoC) on dielectric oil deterioration of the PDT of a private industry client. This will allow EVs to charge while their owners are at work at three different working shifts during the day. In addition, the system is part of an isolated electric grid in a Portuguese Island. A transformer thermal model is utilised in this paper to assess hot-spot temperature by having the information of the load ratio. The data used for the main inputs of the model are the private industry client daily load profile, PDT parameters, the characteristics of the factory and EV parameters. This paper demonstrates that the proposed solution allows avoiding the overloading of the PDT, thus mitigating the loss-of-life, while charging all the EVs plugged-in at the beginning of each working shift.

1. Introduction

Nowadays mobility is ever more a central foundation for countless economic and private activities and as a consequence is an essential part of our life. On the other hand, mobility consumes more and more energy and leads to substantial environmental problems. More than 70% of the transport energy consumption in the European Union (EU-27) (2010) is consequently consumed by road traffic, and more than 90% of such type of energy consumption is based on the use of fossil fuels [1,2]. Common concerns on the subject of urban air pollution, climate change, and dependence on expensive and unstable supplies of fossil fuels have lead researchers and policy makers to look for alternative choices besides to the traditional internal combustion petroleum-fuelled engine vehicles, such as EVs [3,4]. Utilising only RES for charging has the potential to reduce the lifetime carbon dioxide emissions of an EV by at least 80% when compared with the average new vehicle with internal combustion engine [5,6].

EV could bring various benefits, such as lower emissions of several air pollutants and noise, growing energy efficiency when compared to internal combustion engines, and the substitution of fuel as the main primary energy source for road transport [7–9]. A substantial widespread penetration of EVs could also have a great effect on the power system. The effects on the system peak load, power plant dispatch, and carbon emissions rely on both the power plant tools and the EVs charging mode [10].

The usual design horizons for power grids are dozens of years as a result of long service life of grid assets. EVs could produce new

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Nomenclature

d	the daily distance covered by an EV
d_R	the maximum range of the EV
E_i	the initial SOC of an EV battery
g_r	average winding to average oil (in tank) temperature gradient at rated current in K
H	hot-spot factor
i_{P_T}	the total load current
i_R	the rated current
K	load factor (load current/rated current)
k_{11}	thermal model constant
k_{21}	thermal model constant
k_{22}	thermal model constant
L	loss of life
L_L^T	loading limit of the transformer
N	total number of time intervals
n	any given number
P_{EV}	EV rated charging power in W
P_f	factory load in W
P_r	distribution transformer rated power in W
P_{sl}	a pre-set limit
P_T	total load in W
P_Ω	the remaining EV load that is superior to the P_{sl}
R	ratio of load loss to no-load loss at rated current
t	period of the day in time units (h or min)
Δt_n	time interval
V	relative ageing rate
V_n	relative ageing rate during interval n
x	exponential power of total losses versus top-oil (in tank) temperature rise (oil exponent)
y	exponential power of current versus winding temperature rise (winding exponent)
τ_o	average oil time constant
τ_w	winding time constant
μ	the natural logarithmic mean
σ	the standard deviation of the corresponding normal distribution
Θ_a	the average ambient temperature in °C
Θ_o	top-oil temperature in °C
$\Delta\Theta_{o,i}$	top-oil (in tank) temperature rise at start in K
$\Delta\Theta_{o,r}$	top-oil temperature rise at rated current in K
Θ_h	winding hottest-spot temperature in °C
$\Delta\Theta_{h,i}$	hot-spot-to-top-oil (in tank) gradient at start in K
$\Delta\Theta_{h,r}$	hot-spot temperature rise at rated current in K

Indices

a	ambient temperature
d	domestic
EV	electric vehicle
f	factory
h	hot-spot
i	at start/initial
n	index of the time interval
o	top-oil
r	rated load
t	period of the day index in time units [h or min]
w	winding

Table of abbreviations

ACAP	Portuguese automobile association
DN	distribution network
EU-27	European union
EV	electric vehicle
HMI	human–machine interaction
LoL	loss of life
ONAN	oil natural air natural
PDF	probability density function
PDT	power distribution transformer
RES	renewable energy sources
SG	smart grid
SoC	state of charge
V2G	vehicle-to-grid

and unforeseen and sudden load patterns with possibly high simultaneity factors as a result of commuter traffic [10]. Additionally, with a rising number of EVs plugged to power systems for charging, there is also a preoccupation that the distribution networks (DN) already installed could turn out to be extra loaded than predicted compared with the time of their conception. Therefore, reduced implementation of EVs may well result in a reduced effect, however if the penetration total amount of EVs increases, a concrete possibility may occur of local DNs being congested [11,12].

Many EVs charging at the same time could origin grid insufficiencies related with the available capacity and security [13]. Such events can be prevented, if they are correctly incorporated in the grid. If the EVs are operated accordingly – integrating them in the grid could be a substantial and important occasion. Consequently, charging of a high quantity of EVs at the same time can be possible [14]. Devoid of such organised integration, the grid might suffer feeder congestions, excessive voltage drops, line overloads, etc.

Energy systems operation in isolated areas such as islands is often based on the highly costly importation of fossil fuels, which turns out to be a difficult problem with different ramifications including economic, environmental, and confidence of being constantly supplied, with the latest being especially significant for any isolated system such as islands [15,16]. As a result, insular networks that present weaker structures than the mainland ones could be more seriously affected. It is necessary to supply all or at least the most part of the energy demand on site which usually are RES. The penetration of such systems in insular areas are central target of energy policies during the last few years and the design and structure of electric power grids will be forced to change considerably with the recent growing interest in RES [17].

A large shift from the traditional to a new smart grid (SG) networks was witnessed in the last few years. Such kind of transition is converted into an evolution from a typical radial energy flow to novel and systems with an increased complexity, but with better features such as a higher efficiency, a better incidence of distributed generation, better preservation of the environment, and greater reliability. The so called new paradigm of SG is outlining strategies to focus on the energetic needs of this century and afterwards, in order to accomplish such improvements [18]. The notion of SG is getting a noticeable role in both energy research and policy in the European Union [19]. The recent progress in SG research has predicted the connection of distributed RES and EVs to the power network and the numerous technical challenges that come from such a new paradigm and thus have to be approached properly [20].

The implementation of SG paradigm in insular areas has been increasing with the installation of diverse test systems in other islands around the world. Albeit the interconnected power system structure is deemed to be more rigid as regards to stability, isolated