Smart Grid Architecture Model (SGAM):

SGAM is the best approach for the modeling of use cases in a structured manner. The purpose of developing SGAM was to provide an easiest and simplest way to illustrates or visualize the smart grid related functionalities. The SGAM represents how the three-dimensional (zone plane, domain plane, and interoperability layers) architecture is used to describe the use case and sub functionalities of the use case in pictorial form.

SGAM is represented as follows,

1. SGAM domain (one dimensional smart grid plane) shows the stages involved in transmission of power of electrical energy from generation to customers.
2. SGAM zone shows that how the power system management is divided in hieratically way into six zones, namely; process, field, station, operation, enterprise, and market.
3. The interoperability layers represent that how the devices, communication and IT technologies are integrated that belongs to different layers of interoperability.

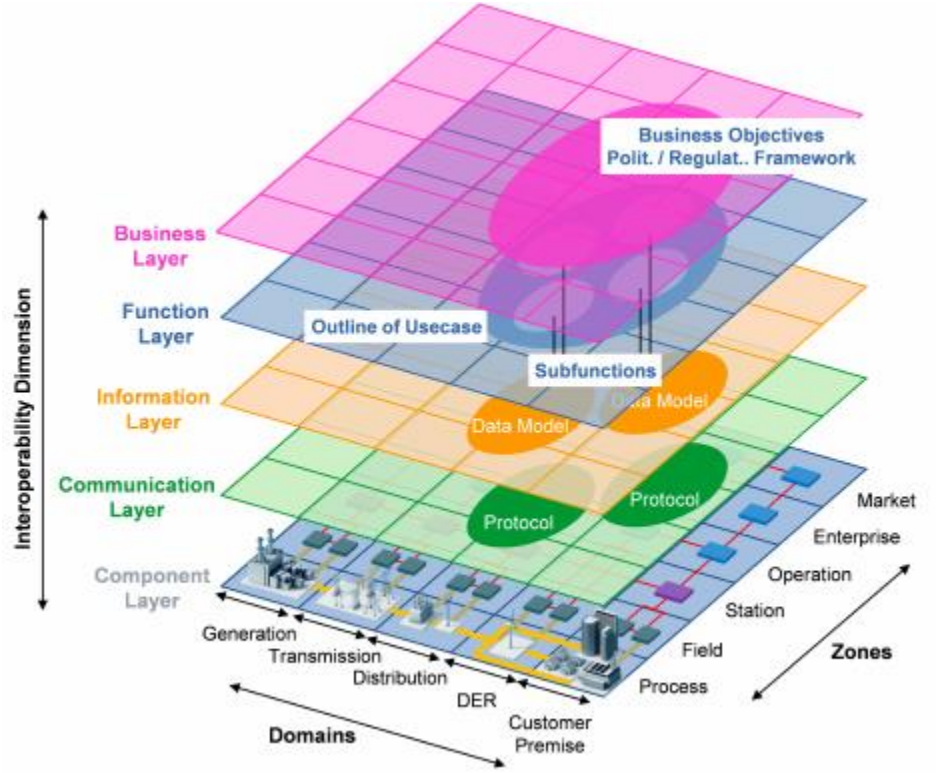


Figure 1: Smart Grid Architecture Model

Interoperability layers: Table 1 shows the functionality of each layer of interoperability.

Layer	Description
Business	This layer maps the use case into SGAM to realize the effect/involvement/role of regulatory and economic markets, policies, and business models.
Function	This layer presents the functions for the use cases in pictorial form as well as the services related to the use case.
Information	This layer describes the exchange of information for function, services and components. This layer represents the information object and canonical data model.
Communication	This layer provides the communication media, protocols and mechanisms for data transmission from the component layer to the process and function layer.
Component	This layer presents the physical components used in SGAM for the use case,which includes power system equipment, communication network infrastructure and computers used for applications.

Table 1 Description of each interoperability layer.

SGAM domain: Table 2 shows the functionality of each layer of domain plane.

Domain	Description
(Bulk) Generation	This layer represents the generation of electricity in bulk quantity. The generators are connected to the transmission system, Examples of generation are power plants (nuclear, hydro, solar power plants) and wind farms.
Transmission	The transmission layer represents the transportation of electricity from Generation to Distribution over long distance.
Distribution	This layer represents the infrastructure for the distribution of electricity to customers.
DER	The DER represent the distributed electricity resources connected at the small scale at homes/hospitals or at industries.These resources may be controlled by DSO or a customer itself.
Customer	It holds the both consumers and prosumers of electricity.

Table 2 Description of each layer of SGAM domain.

SGAM Zone: Table 3 shows the functionality of each layer of zone plane.

Zone	Description
Process	The process shows the transform of energy (electricity, solar, wind, water, heat). The physical components that are involved in process are Generators, transformers, cables, electrical loads, sensors and actuators.
Field	The field consists of the equipment (IEDs) for monitoring and controlling and provides the protection of a process of the power system.
Station	The station is used for data collection, supervision, and substation automation functionalities.
Operation	Hosting power system control operation in respective domains, the operations include monitoring, supervision, estate estimation, controlling and management of electricity production, transmission, distribution, storage and consumption.
Enterprise	It provides commercial and organizational process, services and infrastructure for enterprises(utilities, service providers, energy traders) eg. Asset management, staff training, billing and procurement.
Market	Reflecting the market operations possible along the energy conversion chain. Examples Energy trading, mass market, retail market, etc.,

Table 3 Description of each layer of SGAM domain.

The interoperability layers are modelled in the following section based on the use case i.e to charge an EV efficiently in a single phase under specified grid constraints by coupling the photovoltaic panels and the energy storage device (battery).

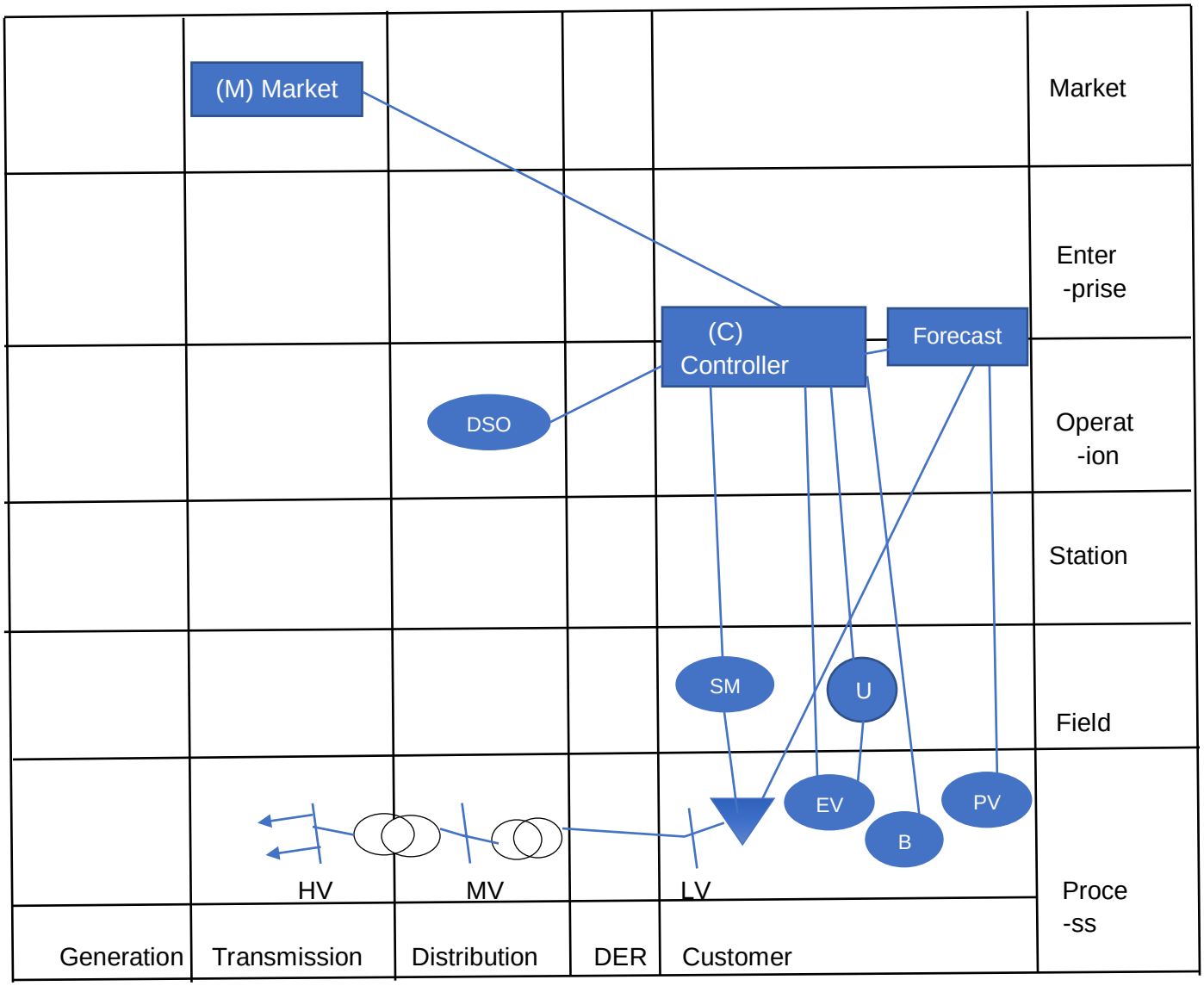
SGAM modelling for the use case:

Component Layer :

The component layer shows the physical devices, components and communication media used for the use cases. The components used in the component layer are,

Component Short name	Component Extended name	Domain	Zone	Reason
C	Controller	Customer	Operation/ Enterprise	It provides monitoring and controlling of entities and provides asset management.

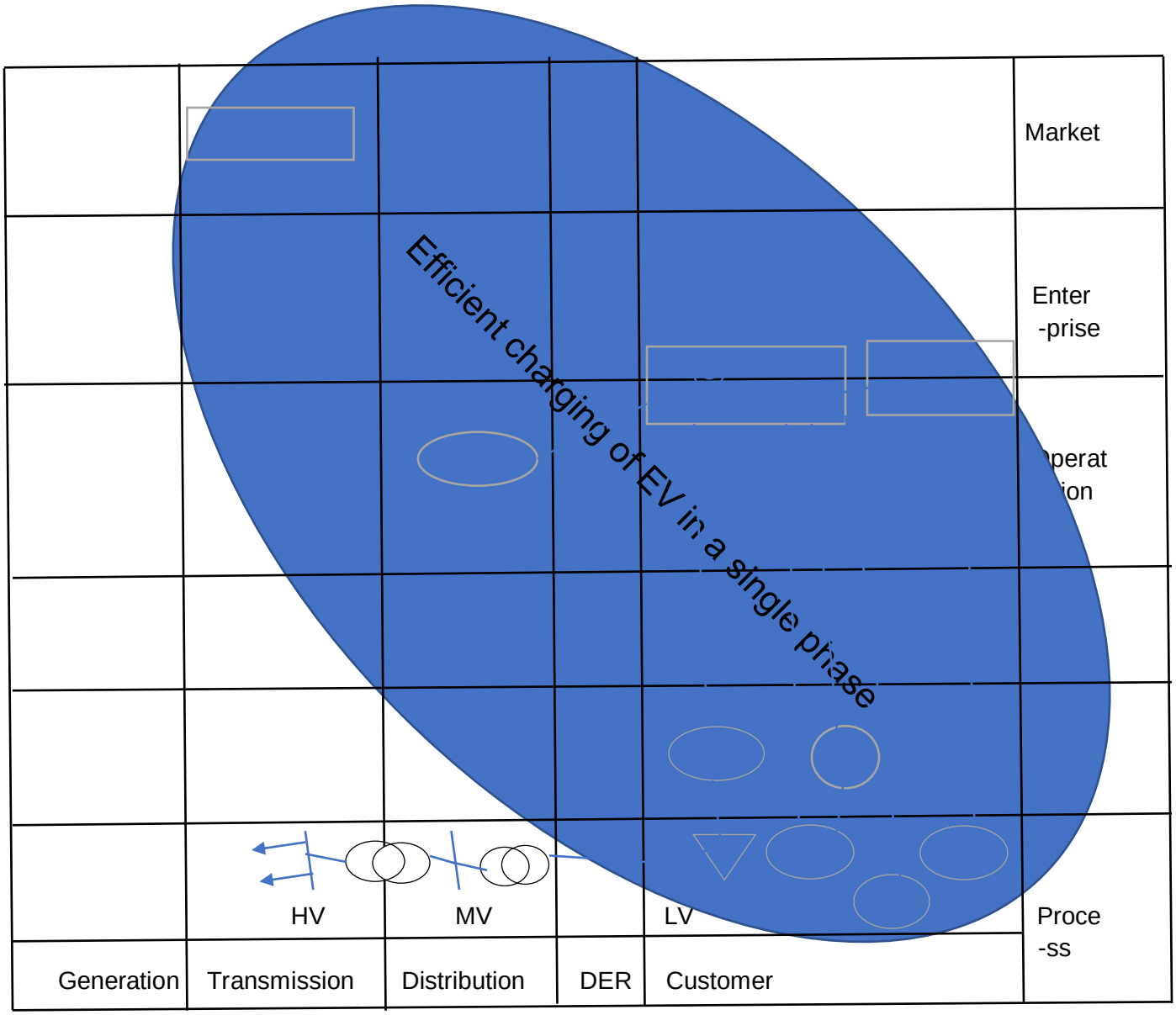
M	Market	Transmission	Market	Reflects the energy market prices.
SM	Smart Meter	Customer	Field	Monitors the electricity usage of a household.
DSO	Distribution System Operator	Distribution	Operation	Power system control in the Distribution domain.
EV	Electric vehicle	Customer	Process	Customers energy transformation
PV	Photovoltaic Panels	Customer	Process	Customers physical energy conversion(solar)
B	Batteries	Customer	Process	Customers energy transformation
U	User	Customer	Field	Monitors Arrival/ Departure time of EV
F	Forecast	Customer	Operation/ Enterprise	Distribution of load profiles from utiity



Business layer:

The business layer defines the business actors and business goals of use cases. The benefits that can be achieved by efficient EV charging use cases are:

1. Cost Optimization by charging EVs during off peak times or by using PV and batteries .
2. Efficient EV charging at 7kw in one phase of a 3-phase system.
3. Scheduling of EV's based on earliest deadline.



The Business layer intends to host the business processes, business objectives, economic and regulatory constraints underlying the use case.

The business layer shows the area affected by the use case and is influenced by its underlying business objectives.

The main objective is to Efficiently charge the EV in a single phase out of 3 phases with the grid constraints.

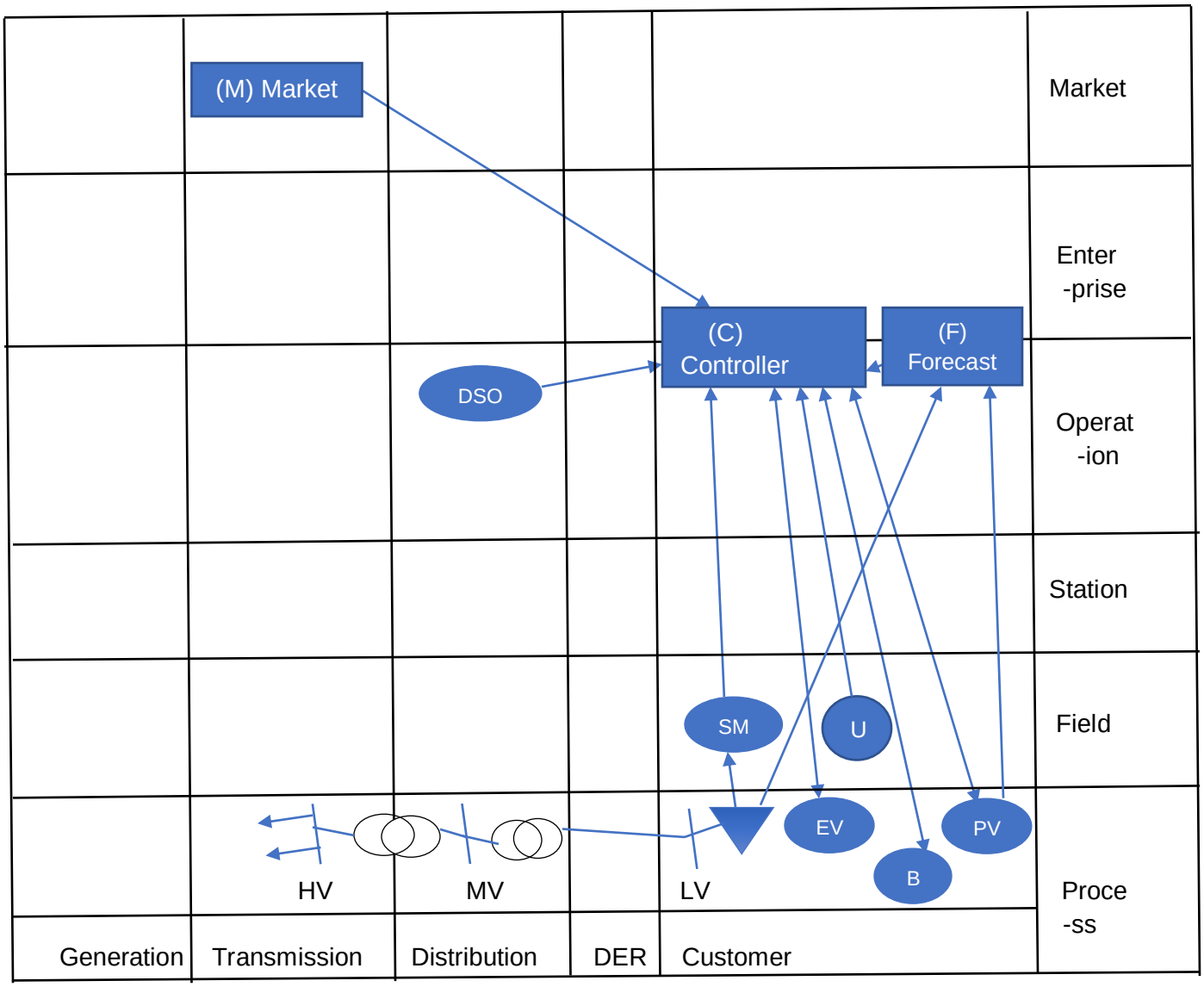
Information layer:

The task of the information layer is to generate object models with identification of supporting standards for data objects for data transmission between different actors.
The information layer presents,

- Business context view (what information is exchanged between actors and enterprise).

Business context view:

The business context view presents that what information is exchanged between actors and systems.

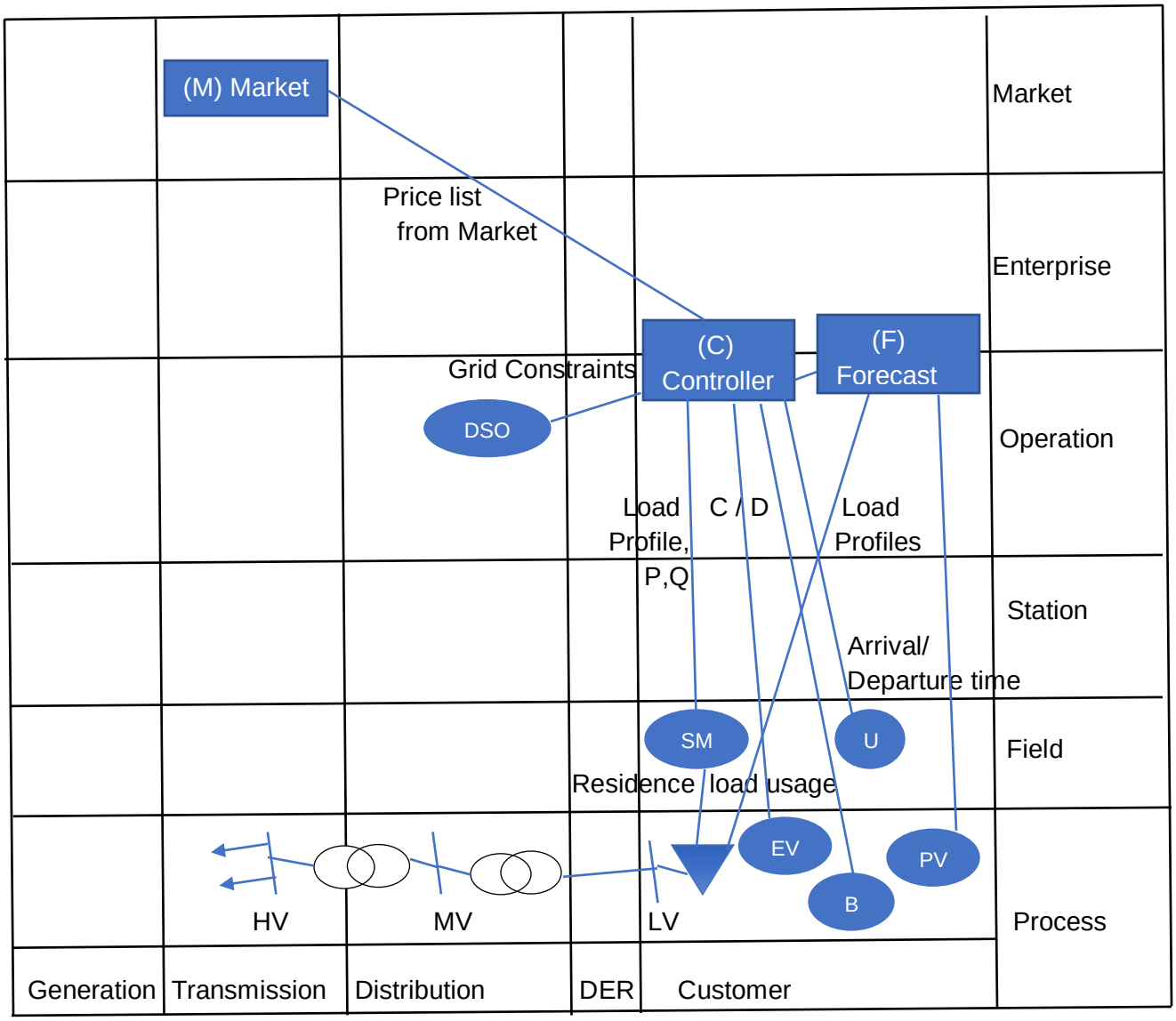


U – voltage
I – current
P – Active power
Q – Reactive power

Information flow from	Information flow to	Information transferred
Smart Meter	Controller	U, I
Forecast	Controller	Load profile
Controller	EV,PV,B	P, Q, charging/discharging of power to grid
Electric Vehicle	Controller	U, I
Photovoltaic panels	Controller and Forecast	U, I and load profile
Batteries	Controller	P, Q
Market	Controller	Price list
DSO	Controller	Grid Constraints (U and I)
User	Controller	Arrival/Departure time
Household	Smart meter and Forecast	U, I and Load profile

Function layer:

The function layer describes the function of each entity/device/ application used in use cases. The goal or focus of the function layer is to support the IT related functionalities, which are used to support the functions of the business layer. The function layer illustrates that how the information is processed and utilized by different actors.



The following table shows the actors and their functionality in this use case.

Actor	Goal	Function in the use case
Smart Meter	Improve the efficiency of electricity supply and reliability of electricity network. Provide data of electric power consumption from supply side and demand side to obtain the intelligent service for power demand.	Provides information about the load consumption, reactive power, active power and the load profiles of a residence
DSO	Power distribution and management of electrical supply. Demand response management. Maintain the reliability of network and increase the efficiency in regular network operation by reducing response time and improving network fault management	Provides with a simple household grid consisting of 3 phase using power factory software (including the grid limitations)
Forecast	Forecasting/ distributing the acquired data to other resources	Forecast the load profiles of PV and household to the controller
Electric Vehicle	EVs achieve 90% energy conversion efficiency. Emits less greenhouse gases. EV costs less to drive than a comparable gas-powered vehicle. Charging during off peak period and discharging during peak periods	EVs are scheduled to optimally charge based on the arrival and departure time of the EVs. EVs perform charging and discharging of power to the grid.
Photovoltaic Panels	Photovoltaic panels, through photoelectric phenomenon, produce electricity in a direct electricity generation way. Solar energy is energy supplied by nature therefore free and abundant. PV panels can provide an effective solution during energy demand.	These provide the available power generated from the solar energy to a phase in which the EV will be charged.
Batteries	Li-ion battery don't require maintenance to ensure their performance. Provides high energy density. The rate of self-discharge is less compared to other rechargeable cells such as Ni-Cad and NiMH forms	These are used to store the energy which is not used during the day in off peak period and is used to charge the EV or to discharge it to the grid.
Controller	Controls all the controllable entities like EV,PV and Batteries. This is used to control the phases of the grid provided by DSO. Receives the market price from energy market.	A heuristic algorithm used to charge the EV efficiently by integrating with PV panels and batteries in a single phase with grid constraints to optimize the cost and for efficient scheduling of multiple EVs
User	User provides the information given by the customer	Provides arrival/departure time of EV's
Market	Obtains the energy market price	Provides the price list to controller.