Abstract

The work presented in this thesis addresses the optimization potential of large PV power plants with respect to energy production during periods of moving clouds. Presently the number and size of utility scale Photo Voltaic (PV) power plants in the megawatt range is increasing and the market for solar inverters is under a severe pressure regarding cost reduction. The main topic of this thesis is the investigation of the potential advantage of applying string inverters with multiple Maximum-Power-Point-trackers (MPPT) in large PV plants compared to the use of one large central inverter with one MPPT. The analysis is based on a comparative investigation of non-uniform irradiation events caused by moving clouds during a period of one year. A set-up for the long term recording of data from the 2.1 MW Danfoss Solar Park in Nordborg (DK) and the 62 kW PV plant at the University of Southern Denmark in Sønderborg (DK) was implemented. A total of 17 PV-inverters have been monitored during a period exceeding one year and the recorded data constitutes the basis of this investigation. A part of the 2.1 MW PV plant was reconfigured to emulate the behavior of a central-inverter and solar panels distributed over a distance of 160 m. In parallel a string based inverter configuration was established with solar panels at the same locations.

An analysis of irradiation data recorded during the test period showed that non-uniform irradiance due to moving clouds is expected to influence the PV plants for less than 4 % of their operational time. The resulting difference in energy production between a system with 3 MPPT and a system with 1 MPPT is calculated for all days where both systems had comparable operational conditions. It can be concluded that both the estimated and the calculated difference in the annual production of energy is in the range <0.3 % and around the limit of what can be registered in the PV plants. It has further been shown theoretically as well as experimentally that landscape variations result in energy production losses.

Two other methods were investigated by applying the recorded data from the 2.1 MW plant. The simulation of a dynamic string allocation concept for fast reallocation of PV strings in parallel show the potential of an increase in annual energy production of up to 0.6 %. The concept allocates PV strings in parallel during periods of low irradiation to avoid low inverter efficiency at low power levels. The effect of a sorting of the panels in the 2.1 MW park has been simulated to show the potential gain by applying PV sorting during the construction of a large PV plant. A sorting of the mounted PV panels is estimated to increase the annual energy production by approximately 0.4%.

A portable IV-scanning instrument for the fast long term characterization of solar panels was developed as part of the project. Each second a sweep of the IV-characteristics of a solar panel is performed and the result stored for later analysis. The instrument is based on an active load, is optimized for field use, is battery operated and has been applied for the characterization of a solar panel over a period of 6 months at the ESTER Outdoor PV monitoring station in Rome, Italy.

Resumé (Danish)

Denne Ph.d. afhandling omhandler optimeringen af energiproduktion fra solcelleanlæg i megawattt klassen under vekslende skydække. Der er de seneste år sket en kraftig forøgelse af sådanne solcelleanlæg og markedet for bl.a. de i markedet benyttede DC-AC omformere (invertere) er under et øget prispres med krav om kostoptimering. Formålet med afhandlingen er primært at undersøge, hvorvidt det med hensyn til energiproduktion er en fordel at anvende streng-omformere med flere "Maximum-Power-Point-Trackers" (MPPT) frem for én central-omformer med én MPPT. Analysen er baseret på undersøgelsen af de forstyrrelser, som skyer forårsager, når de driver ind over anlæggene i løbet af et år. Et omfattende dataopsamlingssystem er installeret på hhv. det 2,1 MW store "Danfoss Solar Park" i Nordborg (DK) samt det 62 kW store solcelleanlæg på Syddansk Universitet i Sønderborg (DK), hvorfra der er opsamlet data fra i alt 17 invertere i over ét år. Disse data udgør grundlaget for denne undersøgelse. En del af det store anlæg blev modificeret til at fungere som en central-inverter med 3 strenge af solcellepaneler fordelt over en 160 m lang strækning, parallelt med en streng-omformer med solcellepaneler placeret på samme måde.

En omfattende analyse af indstrålingsdata fra 2 solcelleanlæg viste at svingende lysintensitet pga. drivende skyer forventes at påvirke anlæggene i under 4 % af deres operative tid. Den deraf resulterende forskel i energiproduktion mellem systemer med én og flere MPPT blev beregnet for de dage, hvor begge testsystemer havde haft ens driftsbetingelser. Der kan konkluderes at både den estimerede og den målte forskel i årlig energiproduktion er i størrelsesordenen <0,3 % og på grænsen af, hvad der kan registreres i anlæggene. Det store solcelleanlæg følger landskabets konturer og det er opstillet en model for vinkelvariationernes indvirkning på energiproduktionen. Det er eksperimentelt eftervist at rækker af solcellepaneler, som har en stor variation i panelvinkel i forhold til vandret, producerer mindre energi i klart vejr end en tilsvarende flad række.

To andre metoder til øgning af den årlige energiproduktion er undersøgt med udgangspunkt i data opsamlet fra det store anlæg. Et koncept med hurtig parallel-kobling af solcellestrenge forventes at kunne forøge den årlige energiproduktion med op til 0,6 %. Dette opnås ved at samle solcellestrenge i parallel på færre omformere ved lav solindstråling for at øge omformerens virkningsgrad. Der er også vist at en sortering af det store anlægs paneler kunne have øget anlæggets energiproduktion med ca. 0,4 % pga. bedre tilpasning mellem de enkelte paneler in solcellestrengene.

En transportabel solpanel IV-kurvetester til langtidskarakterisering af solcellepaneler er udviklet som en del af projektet. Et solcellepanels strøm-spændingskurve måles i ét sekunds intervaller og lagres til senere analyse. Instrument er optimeret til feltbrug/batteridrift. Instrumentet blev anvendt til karakterisering af et solcellepanel gennem 6 måneder på "ESTER Outdoor PV monitoring station" i Rom, Italien.